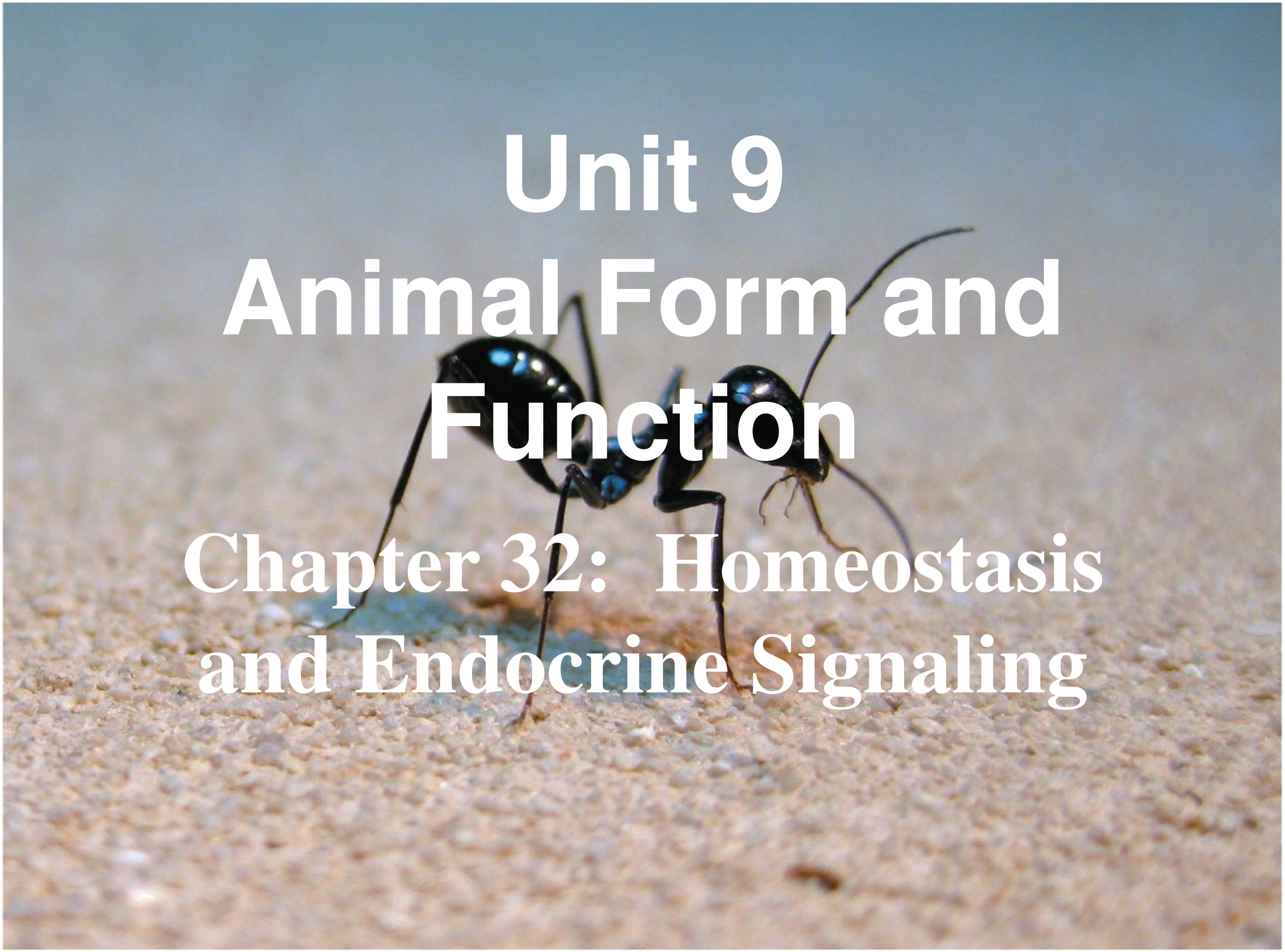


Unit 9 Animal Form and Function

Chapter 32: Homeostasis and Endocrine Signaling

Overview: Diverse Forms, Common Challenges

- **Anatomy** is the study of the biological form of an organism
- **Physiology** is the study of the biological functions an organism performs
- Form and function are closely correlated

Concept 32.1: Feedback control maintains the internal environment in many animals

- Multicellularity allows for cellular specialization with particular cells devoted to specific activities
- Specialization requires organization and results in an internal environment that differs from the external environment

Hierarchical Organization of Animal Bodies

- Cells form a functional animal body through emergent properties that arise from levels of structural and functional organization
- Cells are organized into
  - **Tissues**, groups of cells with similar appearance and common function
  - **Organs**, different types of tissues organized into functional units
  - **Organ systems**, groups of organs that work together
- Note: The simplest animals, such as sponges, lack organs or even true tissues

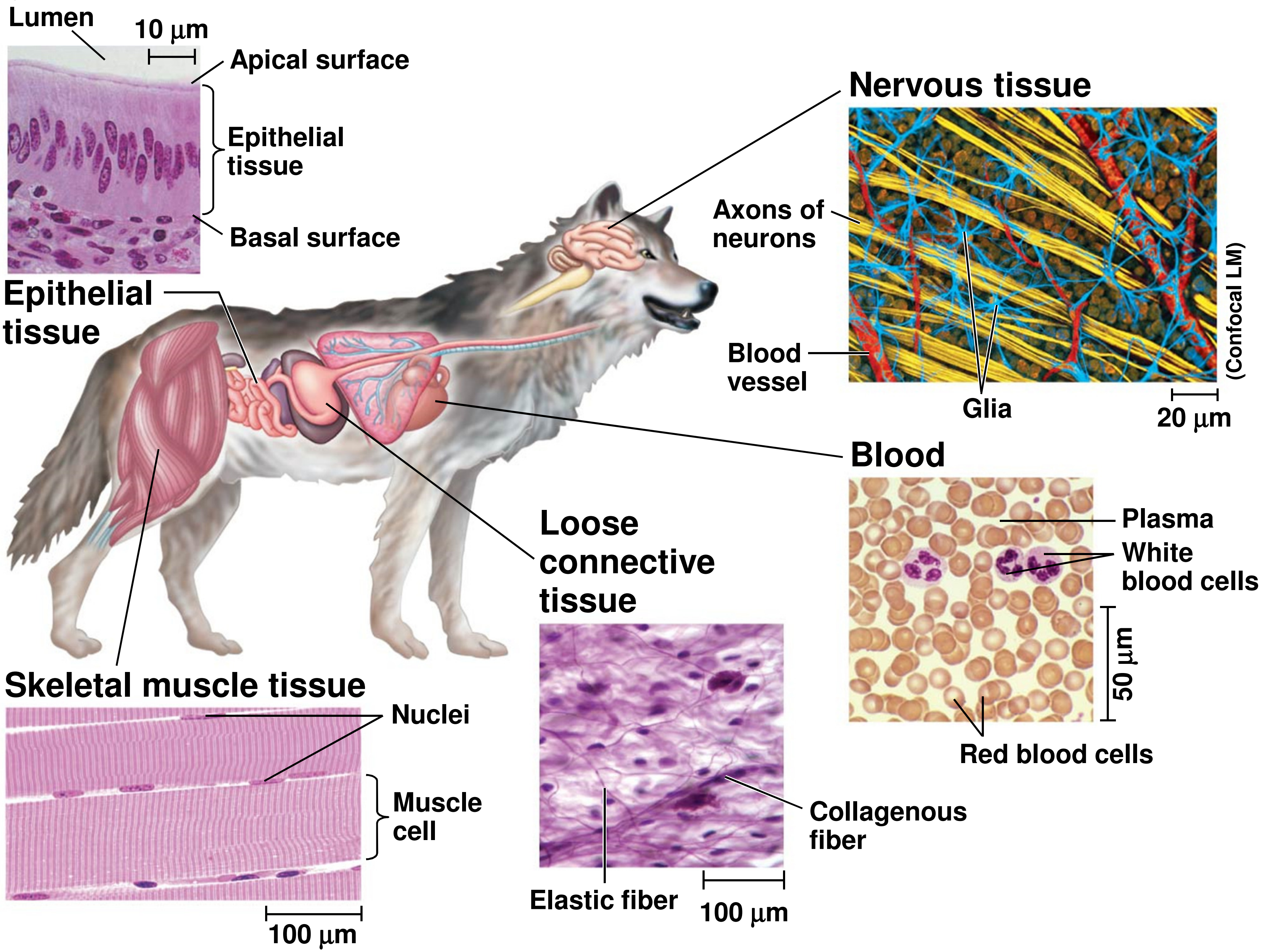
Table 32.1

Table 32.1 Organ Systems in Mammals

Organ System	Main Components	Main Functions
Digestive	Mouth, pharynx, esophagus, stomach, intestines, liver, pancreas, anus	Food processing (ingestion, digestion, absorption, elimination)
Circulatory	Heart, blood vessels, blood	Internal distribution of materials
Respiratory	Lungs, trachea, other breathing tubes	Gas exchange (uptake of oxygen; disposal of carbon dioxide)
Immune and lymphatic	Bone marrow, lymph nodes, thymus, spleen, lymph vessels, white blood cells	Body defense (fighting infections and cancer)
Excretory	Kidneys, ureters, urinary bladder, urethra	Disposal of metabolic wastes; regulation of osmotic balance of blood
Endocrine	Pituitary, thyroid, pancreas, adrenal, and other hormone-secreting glands	Coordination of body activities (such as digestion and metabolism)
Reproductive	Ovaries or testes and associated organs	Reproduction
Nervous	Brain, spinal cord, nerves, sensory organs	Coordination of body activities; detection of stimuli and formulation of responses to them
Integumentary	Skin and its derivatives (such as hair, claws, skin glands)	Protection against mechanical injury, infection, dehydration; thermoregulation
Skeletal	Skeleton (bones, tendons, ligaments, cartilage)	Body support, protection of internal organs, movement
Muscular	Skeletal muscles	Locomotion and other movement

- The specialized, complex organ systems of animals are built from a limited set of cell and tissue types
- Animal tissues can be grouped into four categories
  - Epithelial
  - Connective
  - Muscle
  - Nervous

Figure 32.2



Lumen
10 µm
Apical surface
Epithelial tissue
Basal surface
Epithelial tissue
Nervous tissue
Axons of neurons
Blood vessel
Glia
20 µm
(Confocal LM)
Blood
Plasma
White blood cells
50 µm
Red blood cells
Loose connective tissue
Collagenous fiber
Elastic fiber
100 µm
Skeletal muscle tissue
Nuclei
Muscle cell
100 µm

- **Epithelial tissue**
  - Covers the outside of the body and lines organs and cavities
  - Barrier against mechanical injury, pathogens, and fluid loss
  - *Apical* surface
    - Faces lumen (cavity) or outside of the organ
    - Exposed to fluid or air
  - *Basal* surface
    - Attached to *basal lamina*, separates epithelium from underlining tissue

- **Muscle tissue**
  - Consists of long muscle cells containing actin and myosin that enable muscle to contract
  - 3 types
    - **Skeletal muscle** (aka striated muscle)
      - Attached to bones by tendons
      - Responsible for voluntary movements
    - **Smooth muscle**
      - Has spindle-shaped cells found in the walls of many internal organs
      - Responsible for involuntary activities
    - **Cardiac muscle**
      - Forms contractile wall of the heart
      - Also striated

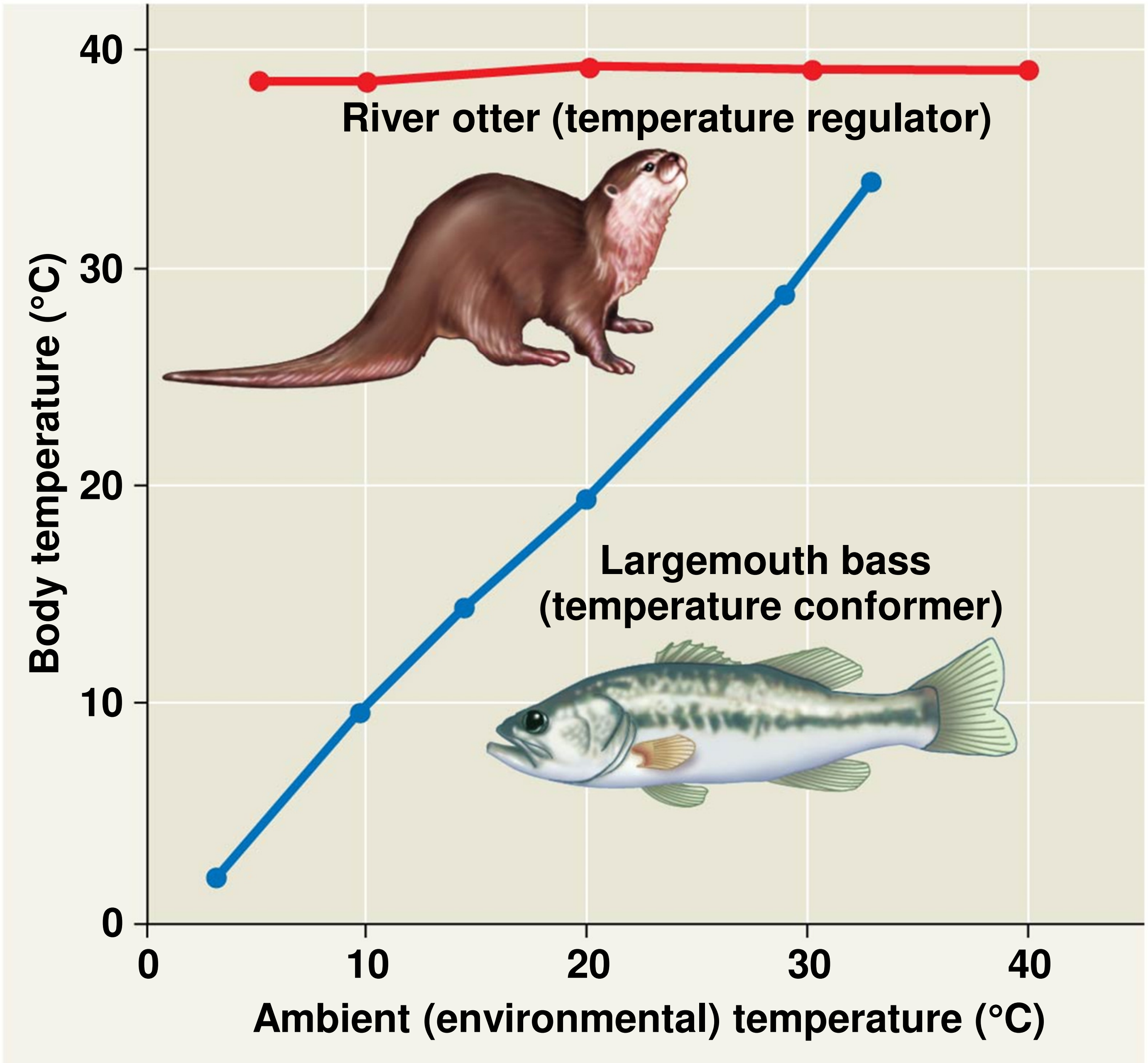
- **Nervous tissue**
  - Functions in the receipt, processing, and transmission of information
  - **Neurons**
    - Basic units of the nervous system
    - Receives nerve impulses via the *cell body* and multiple extensions called *dendrites*
    - Transmits impulses via extensions called *axons*
  - **Glial cells or glia**
    - Support cells
    - Helps nourish, insulate, and replenish neurons

- **Connective tissue**
  - Functions mainly to bind and support other tissues
  - Consists of cells scattered through an extracellular matrix
  - Many forms including
    - Loose connective tissue
      - Holds skin and other organs together
    - Fibrous connective tissue
      - Tendons and ligaments
    - Adipose tissue
      - Stores fat
    - Blood, cartilage, and bone

Regulating and Conforming

- Faced with environmental fluctuations, animals manage their internal environment by either regulating or conforming
- An animal that is a **regulator** uses internal mechanisms to control internal change despite external fluctuation
  - Ex: Otter
- An animal that is a **conformer** allows its internal condition to change in accordance with external changes
  - Ex: Bass

Figure 32.3



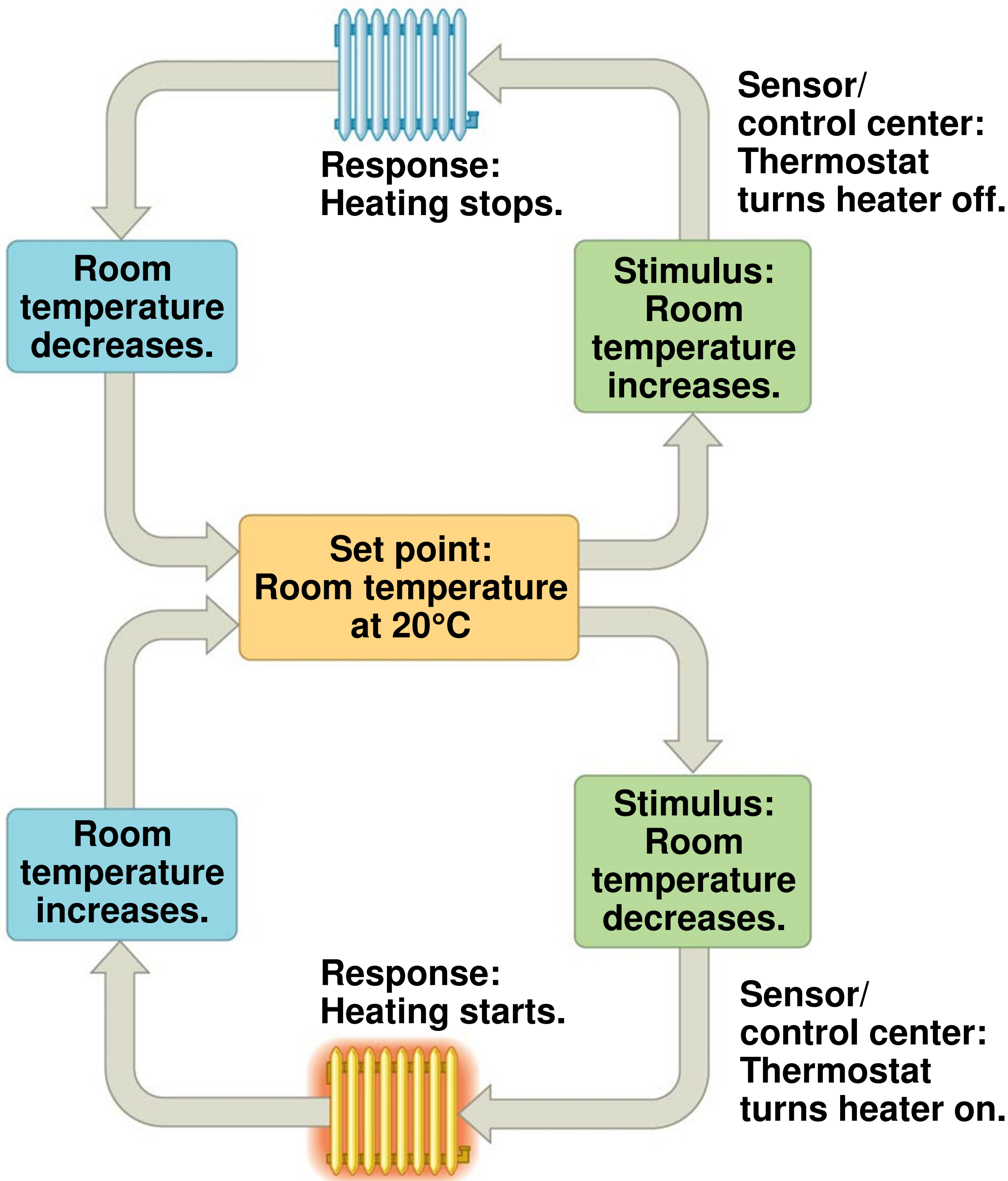
Body temperature (°C)
40
30
20
10
0
River otter (temperature regulator)
Largemouth bass
(temperature conformer)
0
10
20
30
40
Ambient (environmental) temperature (°C)

- An animal may regulate some internal conditions and not others
  - A fish may conform to surrounding temperature in the water
  - But it regulates solute concentrations in its blood and **interstitial fluid**
    - Fluid surrounding body cells

Homeostasis

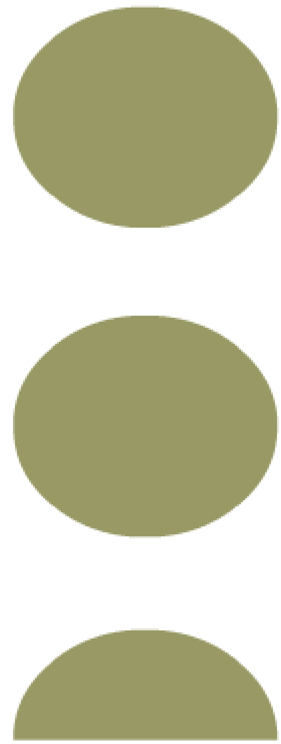
- Organisms use **homeostasis** to maintain a "steady state" or internal balance regardless of external environment
- In humans, each of the following are maintained at a constant level
  - Body temperature (37℃ or 98.6℉)
  - Blood pH (7.4)
  - Glucose concentration (70-110mg /100mL blood)
- Regulation of room temperature by a thermostat is analogous to homeostasis

Figure 32.4


Response:
Heating stops.
Sensor/
control center:
Thermostat
turns heater off.
Room
temperature
decreases.
Stimulus:
Room
temperature
increases.
Set point:
Room temperature
at 20°C
Room
temperature
increases.
Stimulus:
Room
temperature
decreases.
Response:
Heating starts.
Sensor/
control center:
Thermostat
turns heater on.

- Animals achieve homeostasis by maintaining a variable at or near a particular value, or **set point**
- Fluctuations above or below the set point serve as a **stimulus**
  - These are detected by a receptor, or **sensor**
  - Which triggers a **response**
    - Physiological activity that returns the variable to the set point

- Homeostasis in animals relies largely on **negative feedback**
  - Control mechanism that reduces the stimulus
- Homeostasis moderates, but does not eliminate, changes in the internal environment
- Set points and normal ranges for homeostasis are usually stable, but certain regulated changes in the internal environment are essential



Animation: Negative Feedback
Right click slide / Select play

Thermoregulation: *A Closer Look*

- **Thermoregulation** is the process by which animals maintain an internal temperature within a tolerable range
- Body temperature below or above an animal's normal range can
  - Reduce the efficiency of enzymatic reactions
  - Alter fluidity of membranes

Endothermy and Ectothermy

- **Endothermic** animals generate heat by metabolism
  - Birds and mammals
  - Can maintain a stable body temperature in the face of large fluctuations in environmental temperature
- **Ectothermic** animals gain heat from external sources
  - Most invertebrates, fishes, amphibians, and nonavian reptiles
  - May regulate temperature by behavioral means
  - Generally need to consume less food than endotherms, because their heat source is largely environmental

Figure 32.5

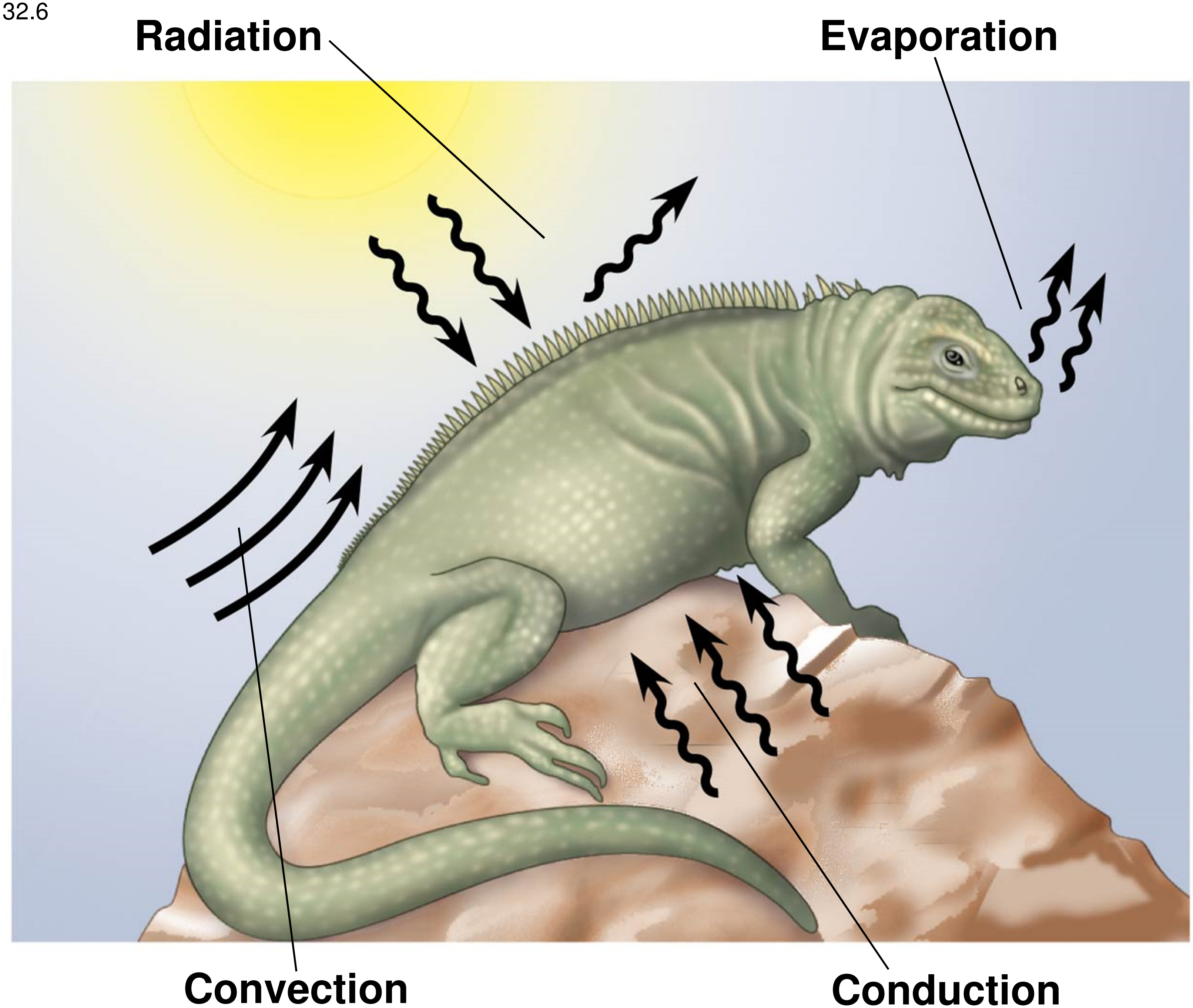
(a) A walrus, an endotherm

(b) A lizard, an ectotherm

Balancing Heat Loss and Gain

- Thermoregulation depends on an animal's ability to control the exchange of heat with its environment
- Organisms exchange heat by four physical processes
  - Radiation, Evaporation, Convection, Conduction
- Heat is always transferred from an object of higher temperature to one of lower temperature
- Numerous adaptations enhance thermoregulation
  - Insulation, hair/feathers, layers of fat, raising fur, "goose bumps"

Figure 32.6

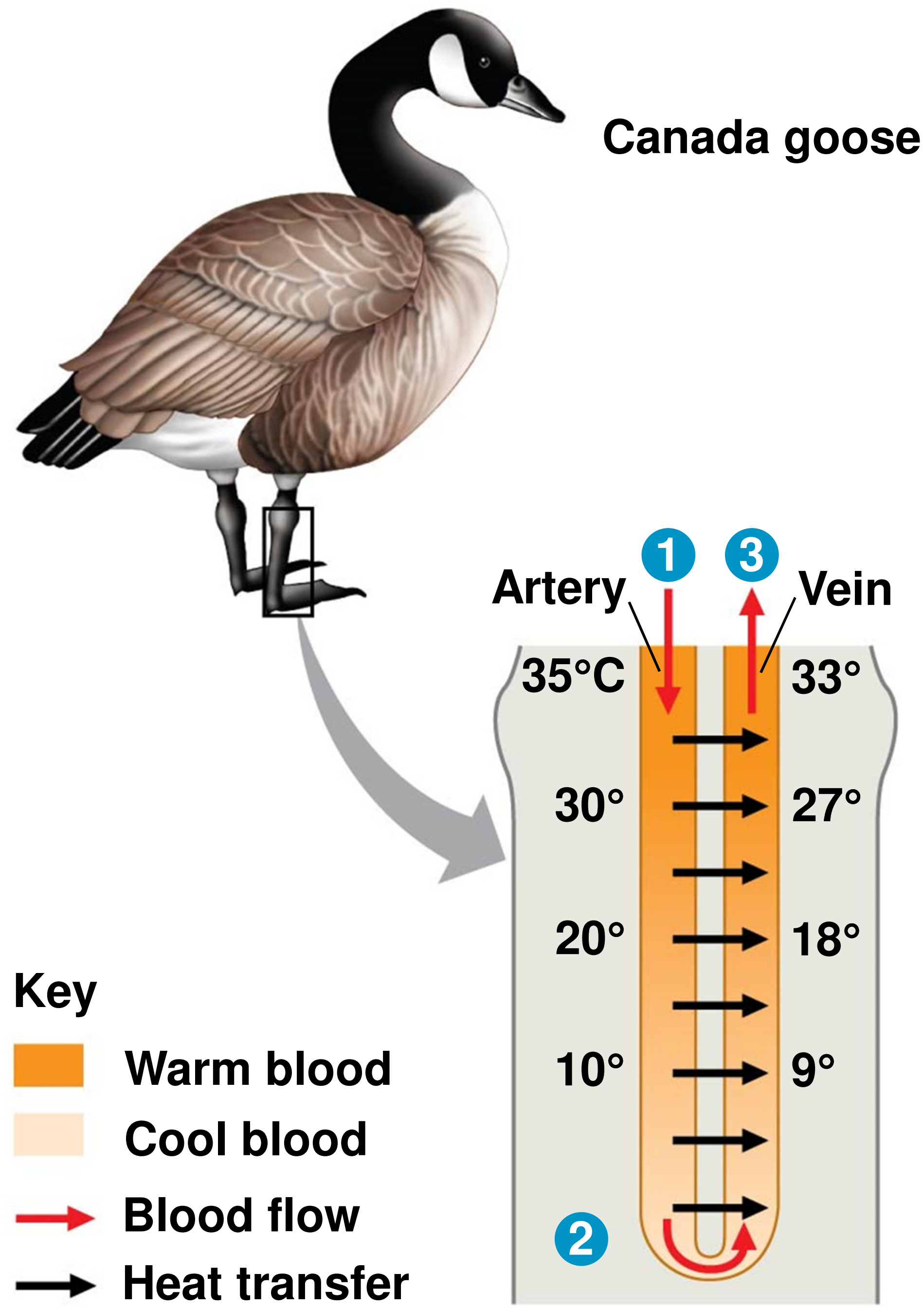


Circulatory Adaptations for Thermoregulation

- In response to changes in environmental temperature, animals can alter blood (and heat) flow between their body core and their skin
  - *Vasodilation* is the widening of the diameter of superficial blood vessels
    - Promotes heat loss
  - *Vasoconstriction* is the narrowing of the diameter of superficial blood vessels
    - Reduces heat loss

- The arrangement of blood vessels in many marine mammals and birds allows for **countercurrent exchange**
  - Transfer of heat between fluids flowing in opposite directions
  - As warm blood moves from the body core in the arteries, it transfer heat to the colder blood returning from the extremities in the veins
    - Reduces heat loss

Figure 32.7



Canada goose
Artery
Vein
1
3
2
35°C
33°
30°
27°
20°
18°
10°
9°
Key
Warm blood
Cool blood
Blood flow
Heat transfer

Acclimatization in Thermoregulation

- Acclimatization is a physiological adjust to environmental changes
  - Birds and mammals can vary their insulation to acclimatize to seasonal temperature changes
    - Ex: Growing thicker fur coat in winter and shedding it in summer
  - Acclimatization in ectotherms often includes adjustments at the cellular level
    - Some ectotherms that experience subzero temperatures can produce “antifreeze” compounds to prevent ice formation in their cells

Physiological Thermostats and Fever

- Thermoregulation in mammals is controlled by a region of the brain called the **hypothalamus**
  - Functions as a thermostat
- The hypothalamus triggers heat loss or heat-generating mechanisms
  - Vasodilation, sweating, panting
  - Vasoconstriction, shivering
- Fever is the result of a change to the set point for a biological thermostat

Figure 32.8a

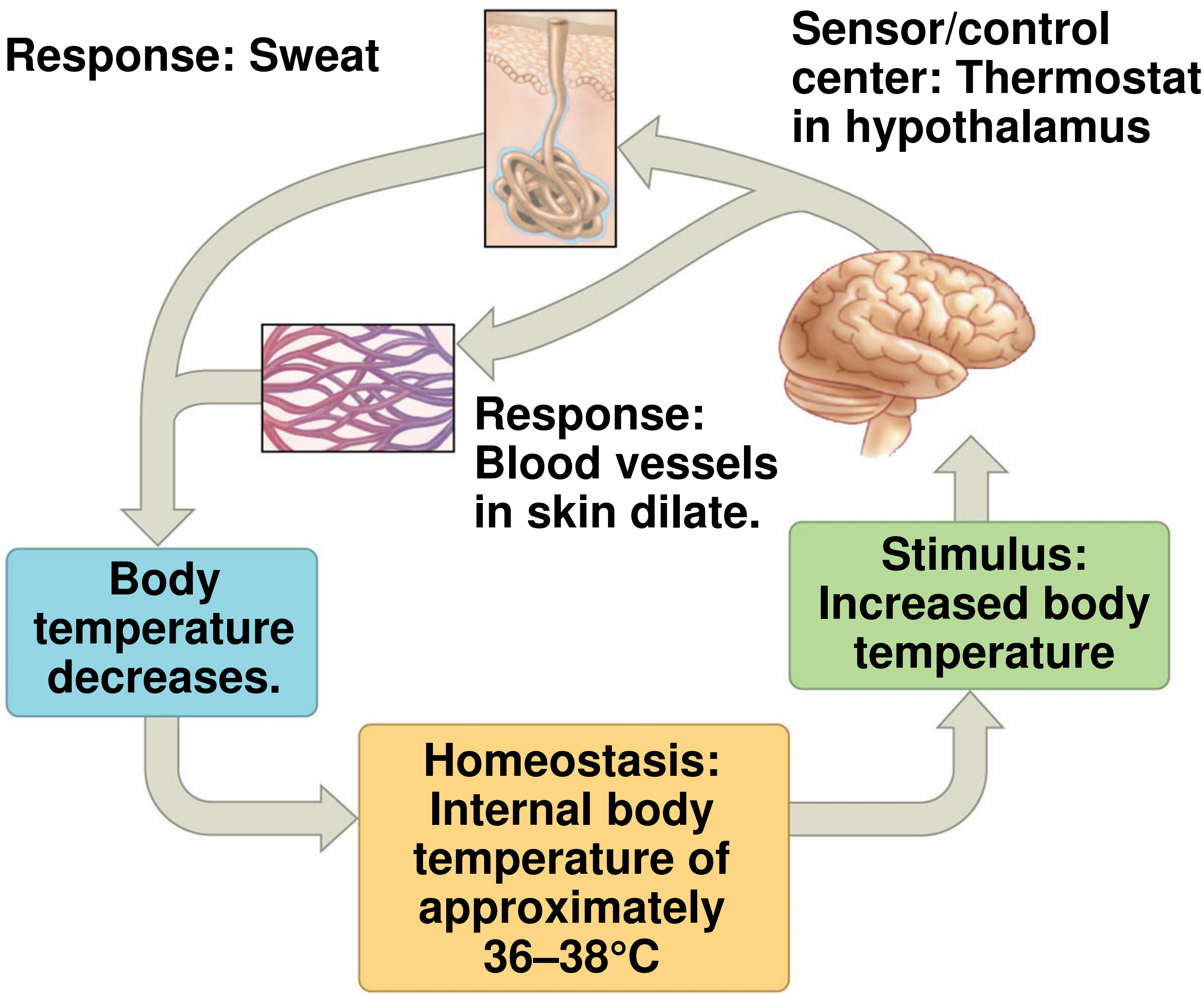
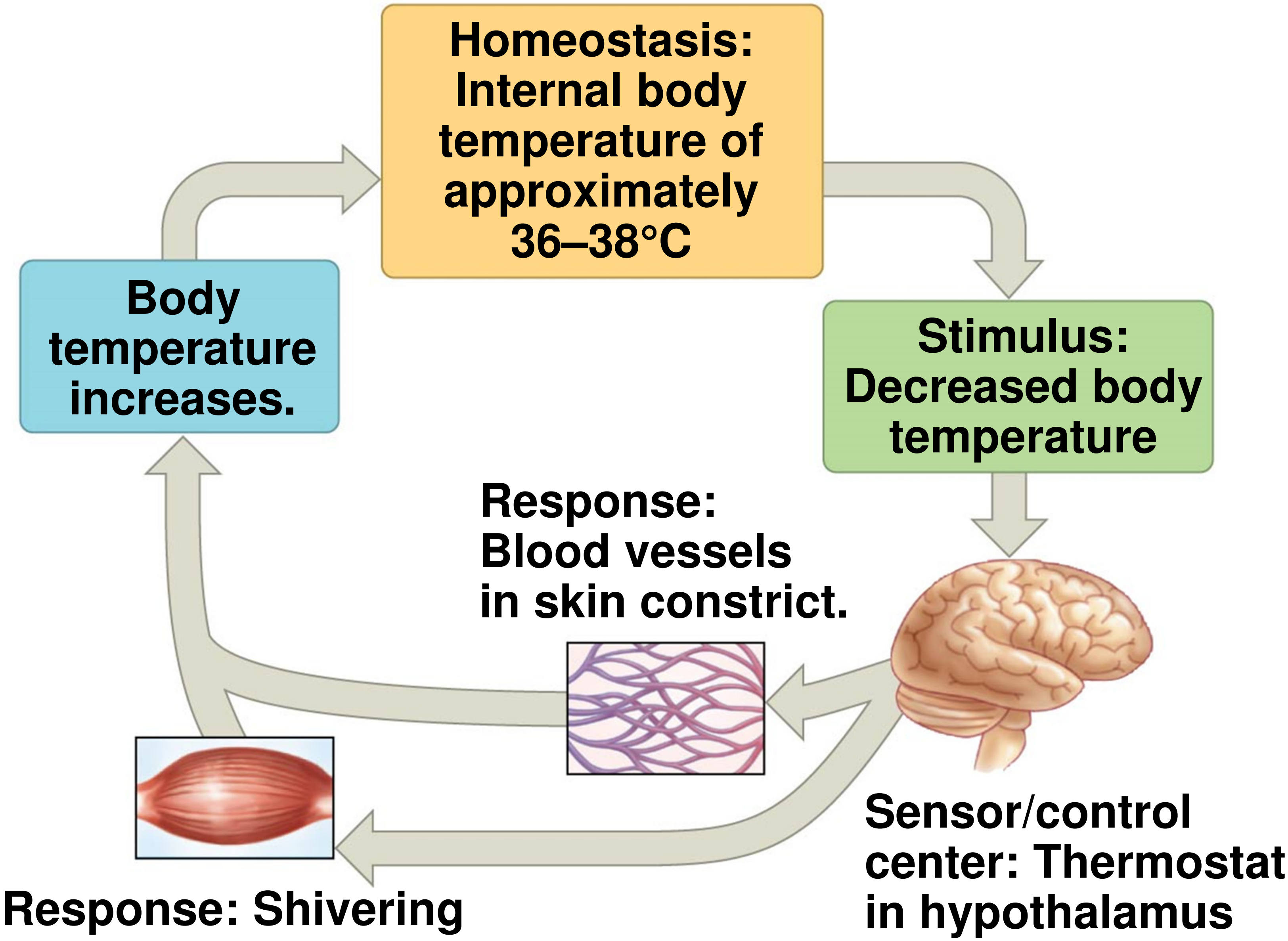

Response: Sweat
Sensor/control center: Thermostat in hypothalamus
Response: Blood vessels in skin dilate.
Stimulus: Increased body temperature
Body temperature decreases.
Homeostasis: Internal body temperature of approximately 36–38°C

Figure 32.8b



Homeostasis: Internal body temperature of approximately 36–38°C
Stimulus: Decreased body temperature
Sensor/control center: Thermostat in hypothalamus
Response: Blood vessels in skin constrict.
Response: Shivering
Body temperature increases.

Concept 32.2: Endocrine signals trigger homeostatic mechanisms in target tissues

- There are two major systems for controlling and coordinating responses to stimuli: the endocrine and nervous systems

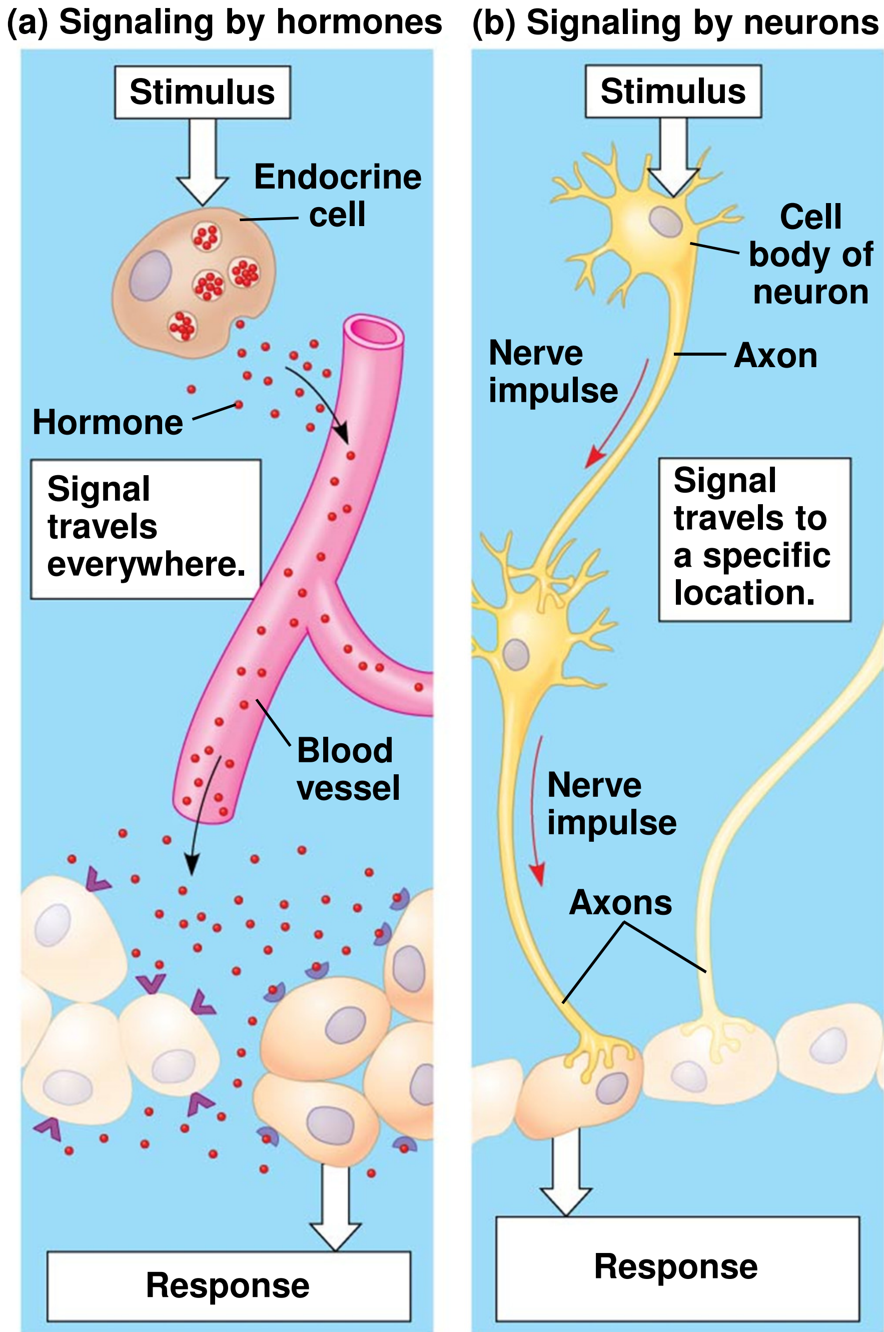
Coordination and Control Functions of the Endocrine and Nervous Systems

- In the **endocrine system**, signaling molecules released into the bloodstream by endocrine cells reach all locations in the body
  - Regardless of where hormones are produced, they reach target cells via the <u>circulatory system</u>
  - Has a domino affect
- In the **nervous system**, neurons transmit signals along dedicated routes, connecting specific locations in the body
  - Specific

- Signaling molecules sent out by the endocrine system are called **hormones**
- Hormones may have effects in a single location or throughout the body
- Only cells with receptors for a certain hormone can respond to it
- Effects are often long-lasting
- The endocrine system is well adapted for coordinating gradual changes that affect the entire body
  - Growth, development, reproduction, metabolic processes, digestion

- In the nervous system, signals called nerve impulses travel along communication lines consisting mainly of axons
- Other neurons, muscle cells, and endocrine and exocrine cells can all receive nerve impulses
- Nervous system communication usually involves more than one type of signal
- The nervous system is well suited for directing <u>immediate</u> and <u>rapid</u> responses to the environment
  - Fast locomotion and behavior

Figure 32.9



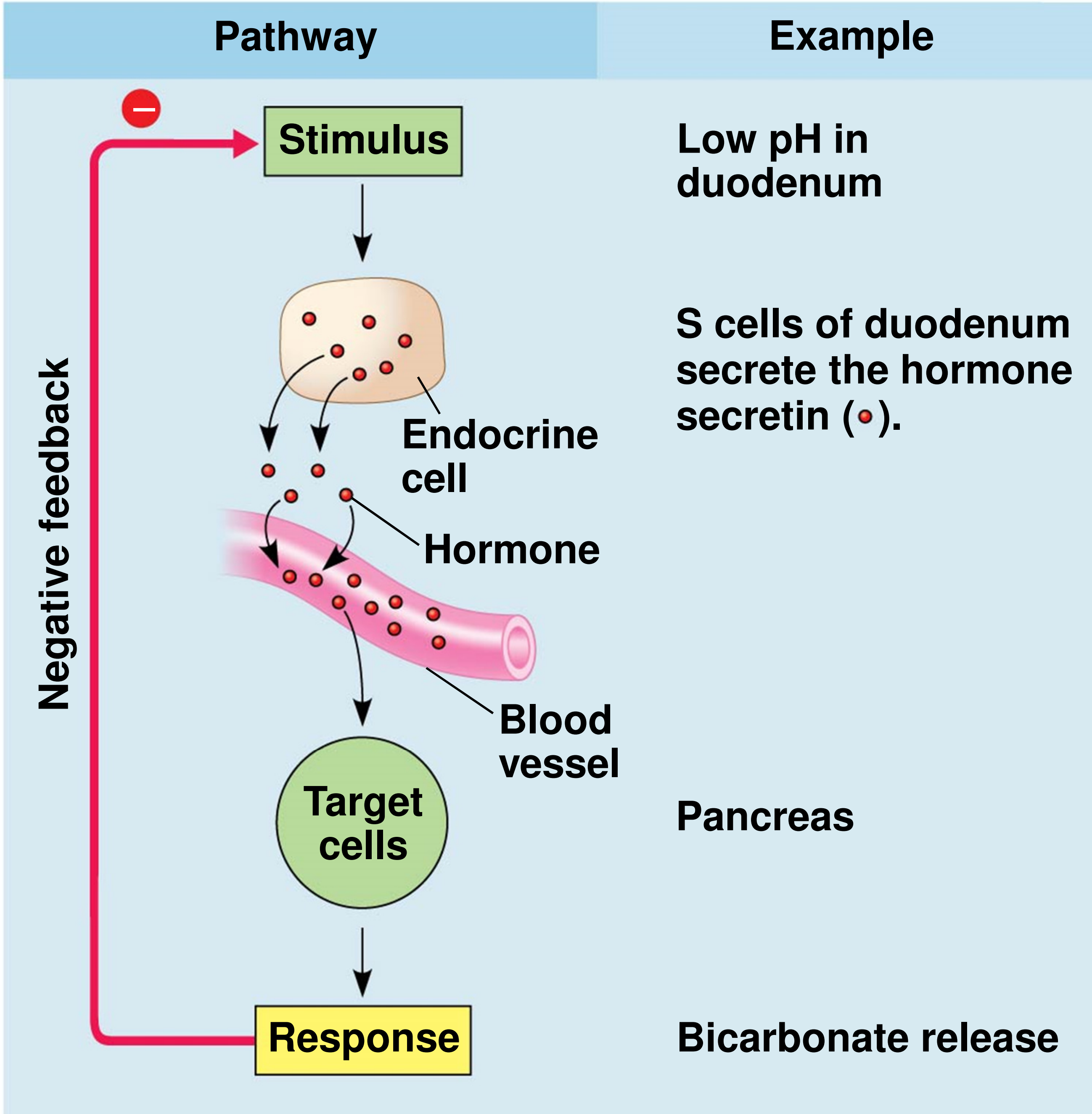
(a) Signaling by hormones
Stimulus
Endocrine cell
Hormone
Signal travels everywhere.
Blood vessel
Response
(b) Signaling by neurons
Stimulus
Cell body of neuron
Nerve impulse
Axon
Signal travels to a specific location.
Nerve impulse
Axons
Response

Simple Endocrine Pathways

- In simple endocrine pathways
  - Endocrine cells respond directly to a stimulus by secreting a particular hormone
  - Hormone travels through bloodstream to target cells
  - Interacts with specific receptors

- Ex: Coordination of pH control in the duodenum relies on an endocrine pathway
  - The release of acidic stomach contents into the duodenum stimulates endocrine cells there to secrete the hormone secretin
  - This causes target cells in the **pancreas** to raise the pH in the duodenum
  - The pancreas can act as
    - An *exocrine gland*, secreting substances through a duct
    - An *endocrine gland*, secreting hormones directly
      into interstitial fluid

Figure 32.10



Pathway
Example
Stimulus
Low pH in duodenum
Endocrine cell
S cells of duodenum secrete the hormone secretin (•).
Hormone
Blood vessel
Negative feedback
Target cells
Pancreas
Response
Bicarbonate release

Neuroendocrine Pathways

- Hormone pathways that respond to stimuli from the external environment rely on a sensor in the nervous system
  - In vertebrates, the hypothalamus integrates endocrine and nervous systems
- Signals from the hypothalamus travel to a gland located at its base, called the **pituitary gland**

- Hormonal signals from the hypothalamus trigger synthesis and release of hormones from the **anterior pituitary**
  - Hormone cascade pathway (domino effect)
- The **posterior pituitary** is an extension of the hypothalamus
  - Secretes **oxytocin**
    - Regulates release of milk during nursing in mammals
  - Also secretes **antidiuretic hormone** (**ADH**)

Figure 32.12

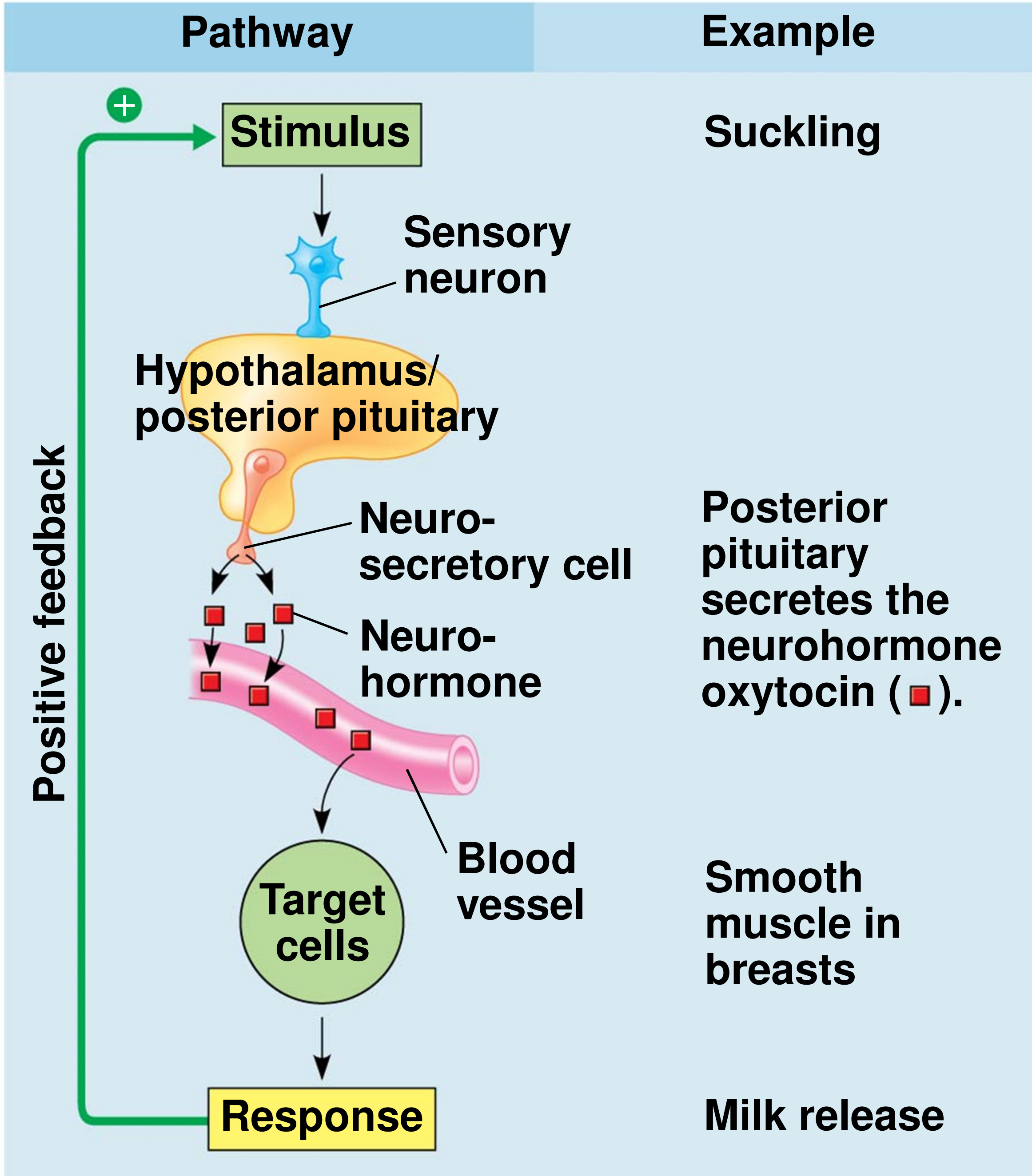

Pathway
Example
Stimulus
Suckling
Sensory neuron
Hypothalamus/ posterior pituitary
Neuro- secretory cell
Posterior pituitary secretes the neurohormone oxytocin ( ).
Neuro- hormone
Positive feedback
Blood vessel
Target cells
Smooth muscle in breasts
Response
Milk release

Figure 32.11a

Major Endocrine Glands and Their Hormones

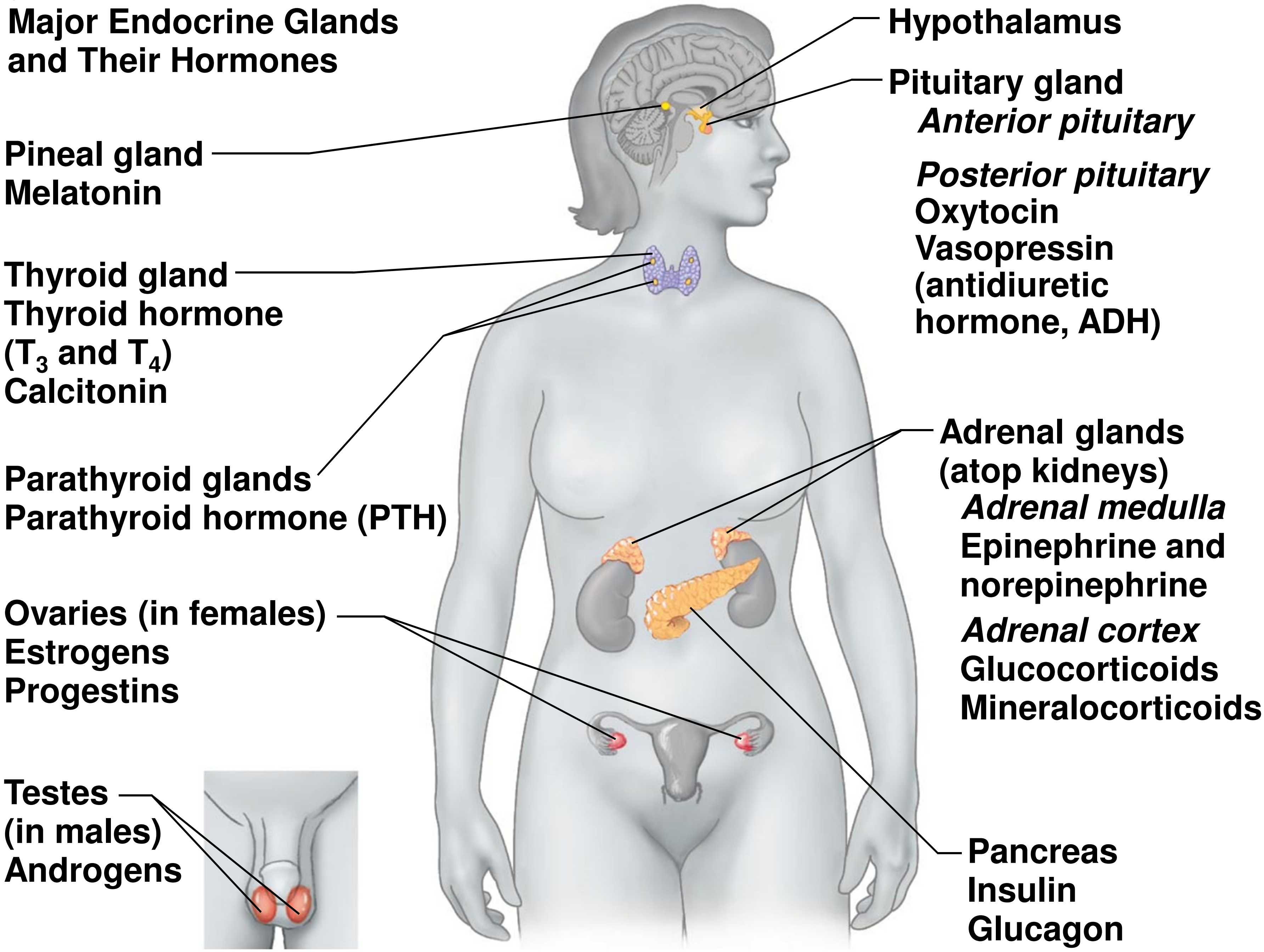


Figure 32.11b

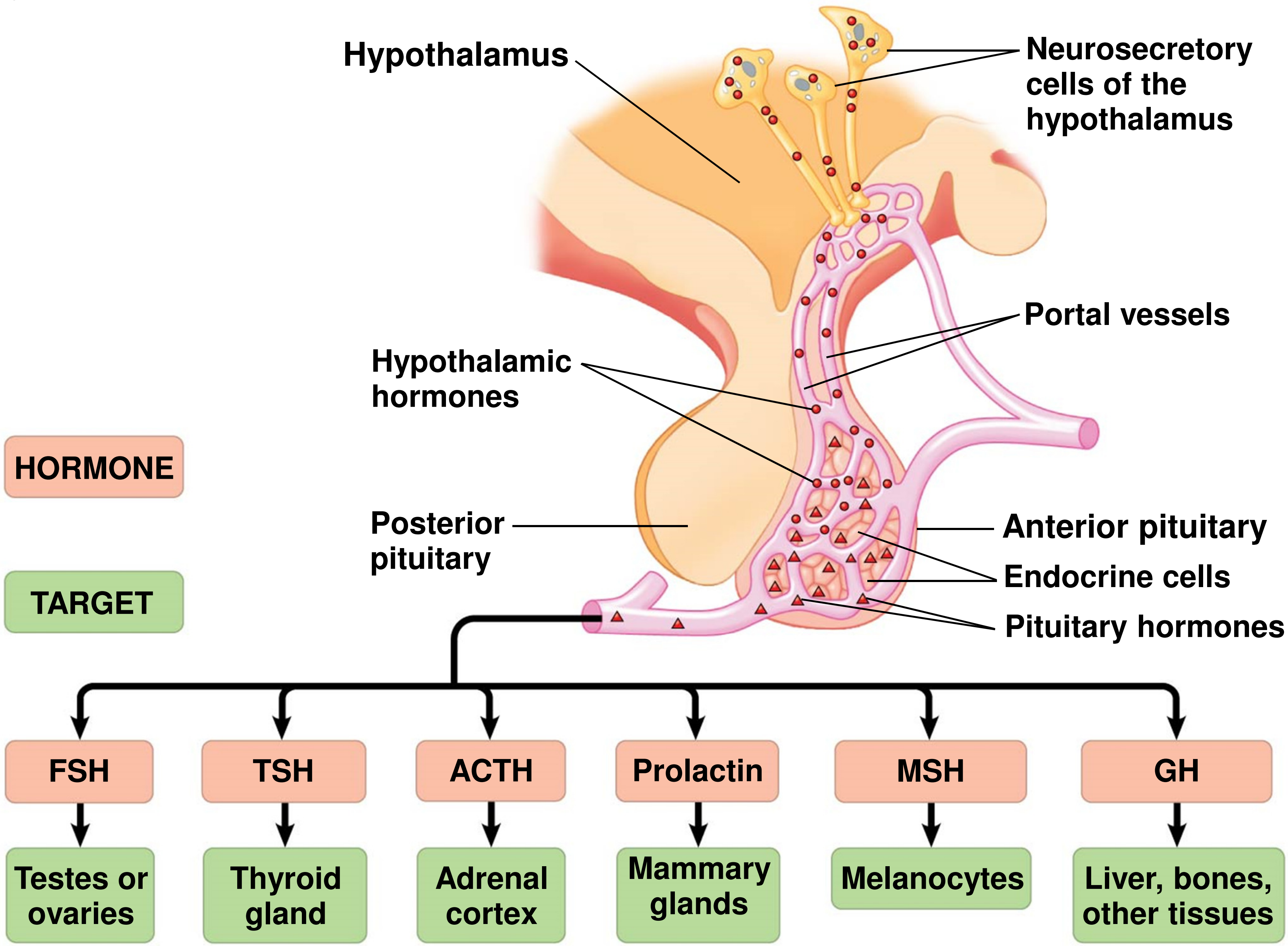
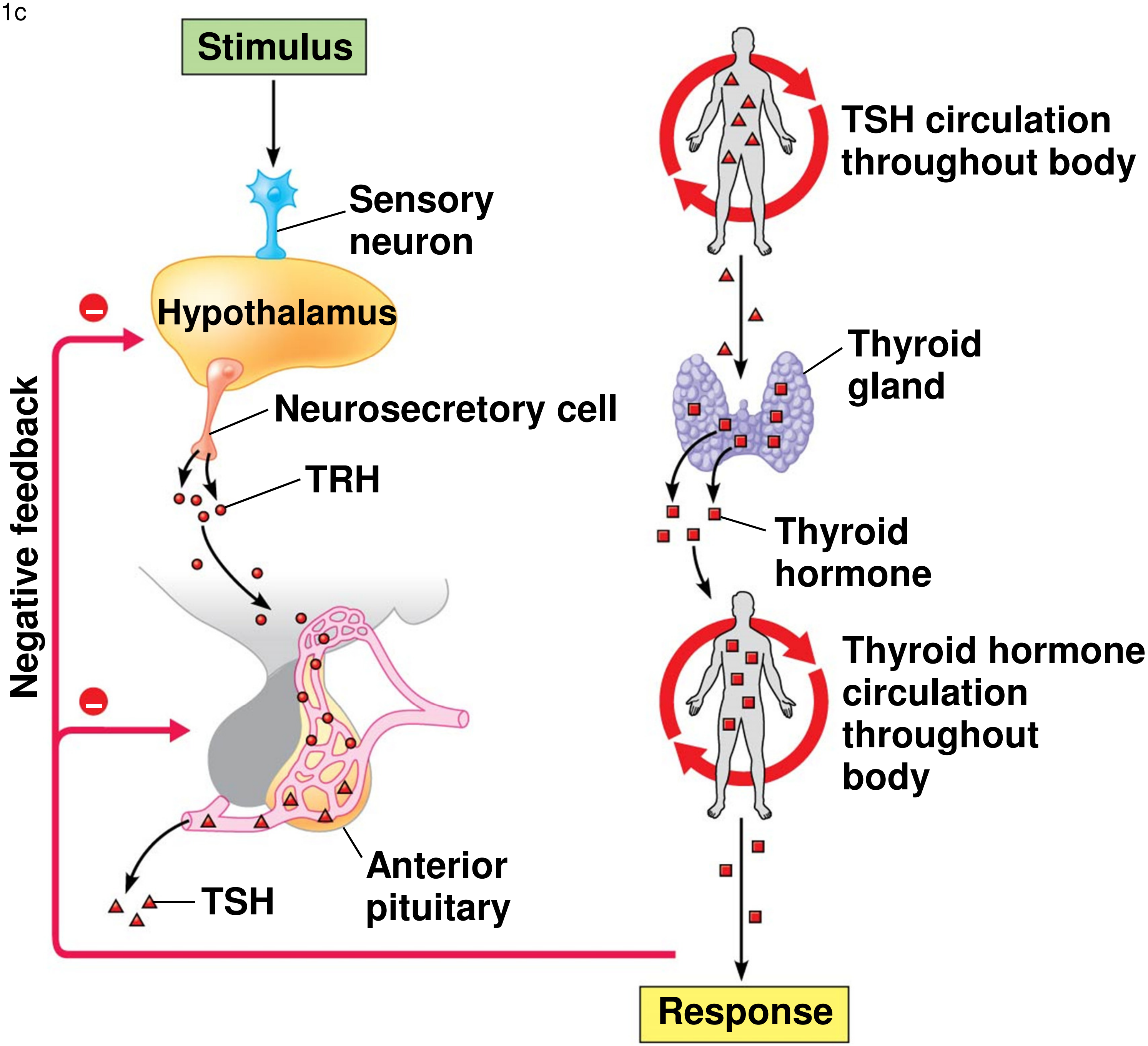


Figure 32.11c



Feedback Regulation in Endocrine Pathways

- A feedback loop links the response back to the original stimulus in an endocrine pathway
- While negative feedback dampens a stimulus, **positive feedback** reinforces a stimulus to increase the response
  - In animals, positive feedback loops do not play a major role in homeostasis
  - But help drive processes to completion

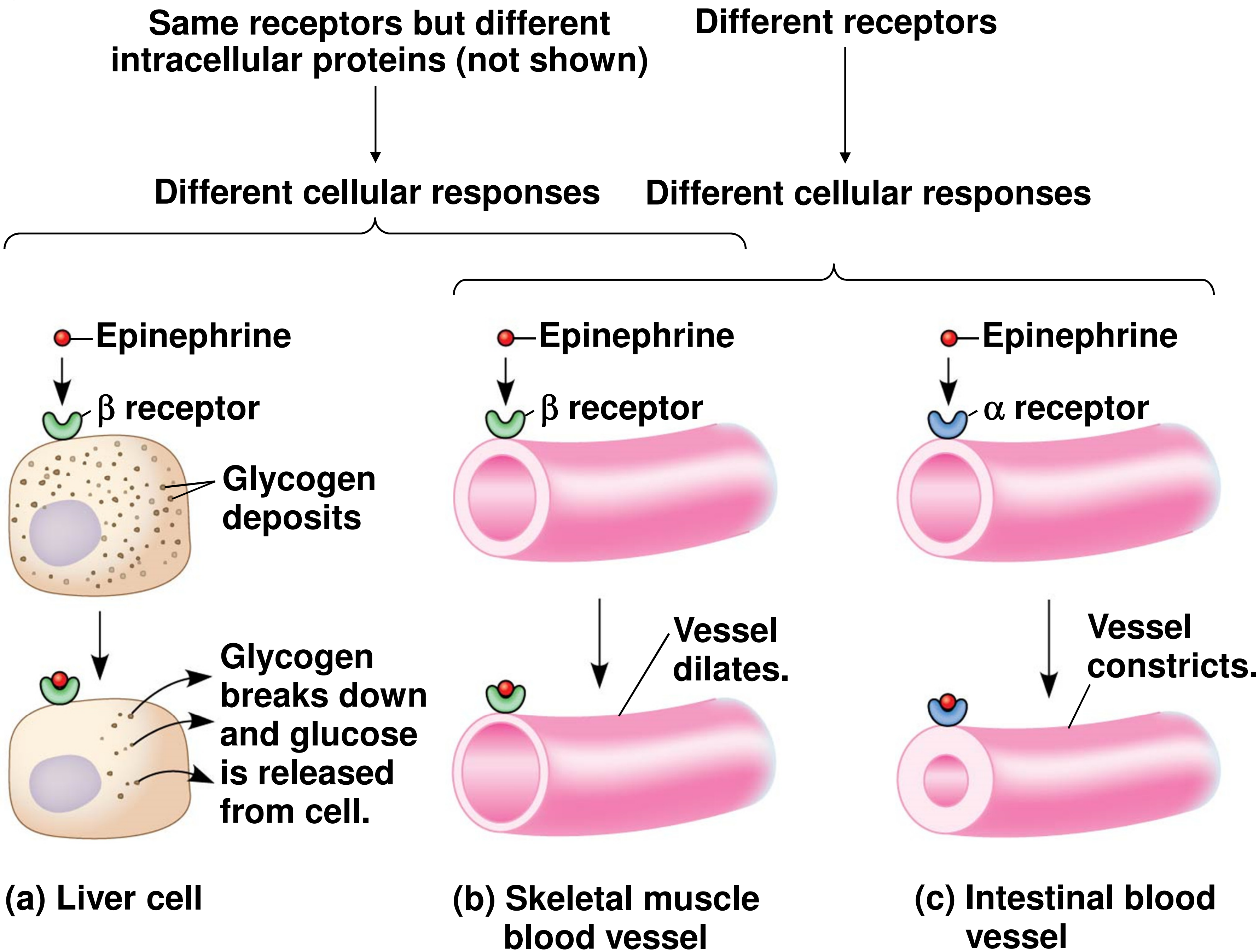
Pathways of Water-Soluble and Lipid-Soluble Hormones

- The hormones discussed thus far are water soluble proteins that bind to cell-surface receptors and that trigger events leading to a cellular response
  - The intracellular response is called *signal transduction*
  - A signal transduction pathway typically has multiple steps
- Lipid-soluble hormones have receptors inside cells
  - When bound by the hormone, the hormone-receptor complex moves into the nucleus
  - There, the receptor alters transcription of particular genes

Multiple Effects of Hormones

- Many hormones elicit more than one type of response
  - Ex: **Epinephrine** is secreted by the adrenal glands
    - Can raise blood glucose levels
    - Increase blood flow to muscles
    - Decrease blood flow to the digestive system
- Target cells vary in their response to a hormone because they differ in their receptor types or in the molecules that produce the response

Figure 32.13


Same receptors but different intracellular proteins (not shown)
Different receptors
Different cellular responses
Different cellular responses
Epinephrine
β receptor
Glycogen deposits
Glycogen breaks down and glucose is released from cell.
(a) Liver cell
Epinephrine
β receptor
Vessel dilates.
(b) Skeletal muscle blood vessel
Epinephrine
α receptor
Vessel constricts.
(c) Intestinal blood vessel

Concept 32.3: A shared system mediates osmoregulation and excretion in many animals

- **Osmoregulation** is the general term for the processes by which animals
  - Control solute concentrations in the interstitial fluid
  - Balance water gain and loss
- **Excretion** is the process that rids the body if waste products

Osmosis and Osmolarity

- Cells require a balance between uptake and loss of water
  - Water enters and leaves cells by osmosis
- **Osmolarity** is the solute concentration of a solution
  - Determines the movement of water across a selectively permeable membrane
- If two solutions are *isoosmotic*, the movement of water is equal in both directions
- If two solutions differ in osmolarity, the net flow of water is from the hypoosmotic to the hyperosmotic solution
  - *Hyperosmotic* solution has greater concentration of solutes
  - *Hypoosmotic* solution is more dilute

Osmoregulatory Challenges and Mechanisms

- **Osmoconformers** are isoosmotic with their surroundings and do not regulate their osmolarity
  - All osmoconformers are marine animals
- **Osmoregulators** expend energy to control water uptake and loss in a hyperosmotic or hypoosmotic environment

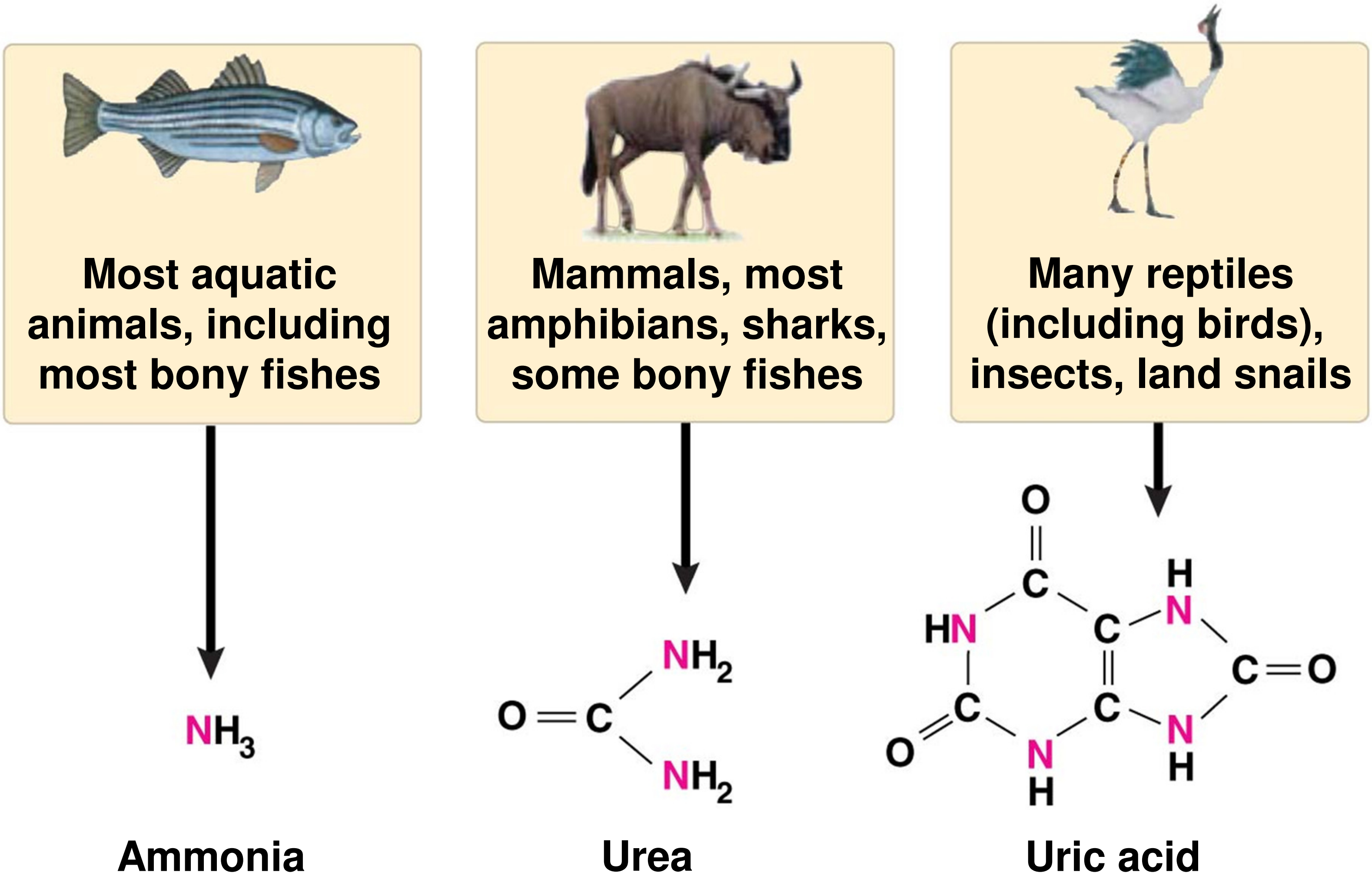
- Marine and freshwater organisms have opposite challenges
  - Marine fish drink large amounts of seawater to balance water loss and excrete salt through their gills and kidneys
  - Freshwater fish drink almost no water and replenish salts through eating
    - Some also replenish salts by uptake across the gills

- Land animals have mechanisms to prevent dehydration
  - Most have body coverings that help reduce water loss
  - They drink water and eat moist foods, and they produce water metabolically

Nitrogenous Wastes

- The type and quantity of an animal's waste products may greatly affect its water balance
- Among the most significant wastes are nitrogenous breakdown products of proteins and nucleic acids
- Some animals convert toxic **ammonia** (NH_3) to less toxic compounds prior to excretion
  - Urea or uric acid

Figure 32.16a



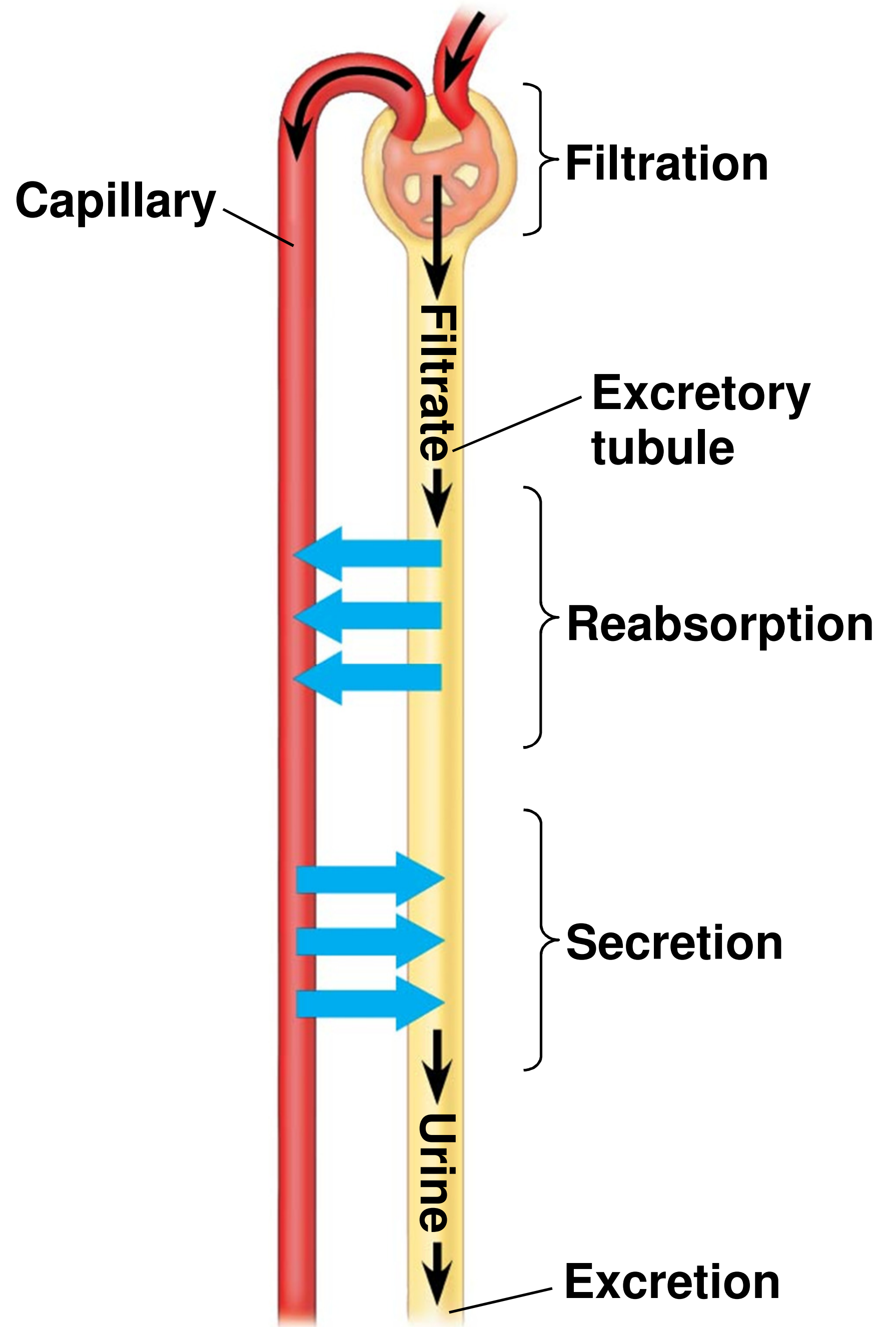
- Ammonia excretion is most common in aquatic organisms
- Vertebrates excrete **urea**, a conversion product of ammonia, which is much less toxic
- Insects, land snails, and many reptiles including birds excrete **uric acid** as a semisolid paste
  - Less toxic than ammonia and generates very little water loss, but it is energetically more expensive to produce than urea

Excretory Processes

- In most animals, osmoregulation and metabolic waste disposal rely on **transport epithelia**
  - Layers of epithelial cells that are specialized for moving solutes in controlled amounts in specific directions
- Many animal species produce urine by refining a **filtrate** derived from body fluids

- Key functions of most excretory systems
  - **Filtration**: Filtering of body fluids
  - **Reabsorption**: Reclaiming valuable solutes
  - **Secretion**: Adding nonessential solutes and wastes from the body fluids to the filtrate
  - **Excretion**: Releasing processed filtrate containing nitrogenous wastes from the body

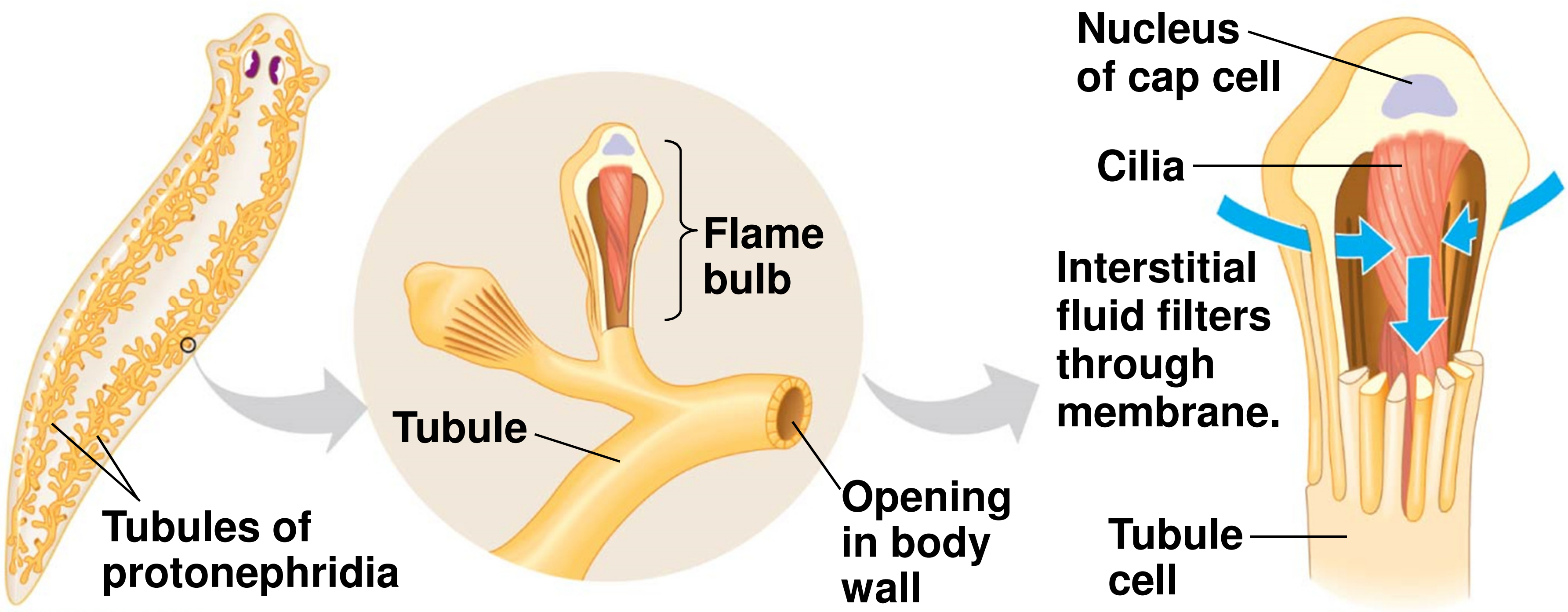
Figure 32.17


Capillary
Filtration
Filtrate
Excretory tubule
Reabsorption
Secretion
Urine
Excretion

Invertebrates

- Flatworms have excretory systems called *protonephridia*
  - Networks of dead-end tubules connected to external openings
- The smallest branches of the network are capped by a cellular unit called a *flame bulb*
- These tubules excrete a dilute fluid and function in osmoregulation

Figure 32.18


Tubules of protonephridia
Flame bulb
Tubule
Opening in body wall
Nucleus of cap cell
Cilia
Interstitial fluid filters through membrane.
Tubule cell

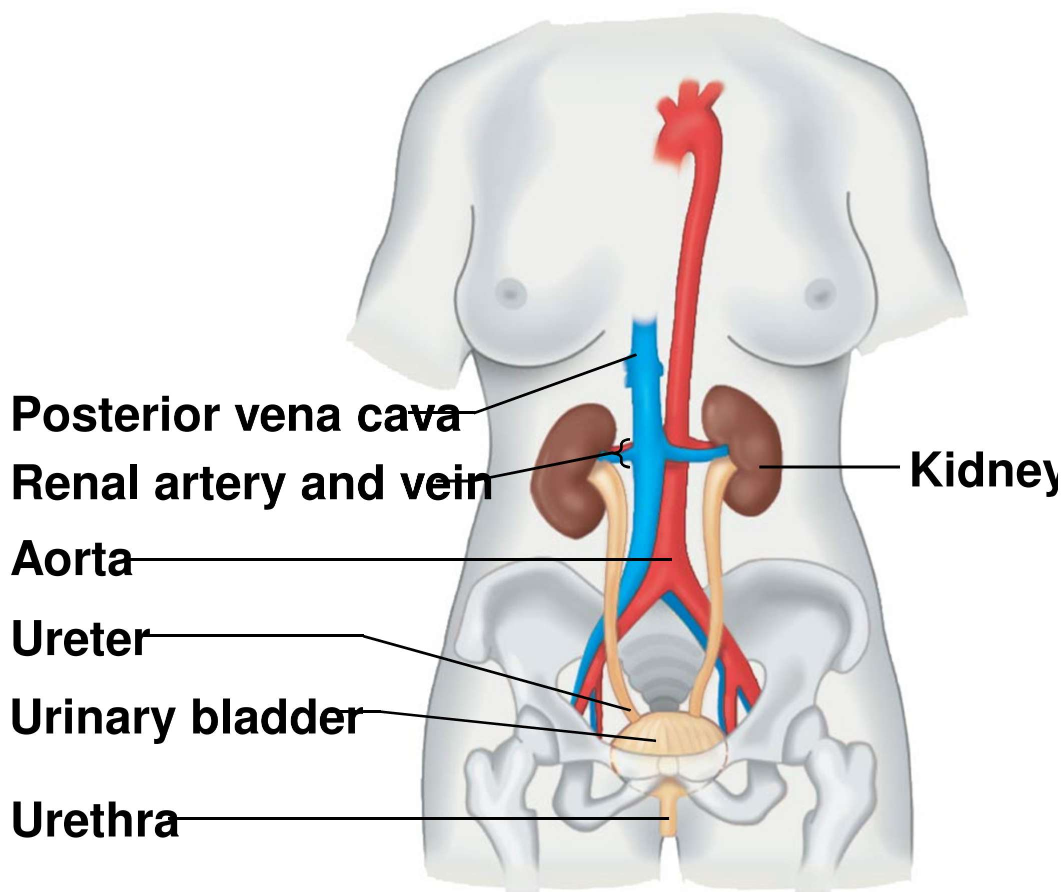
- In insects and other terrestrial arthropods, *Malpighian tubules* remove nitrogenous wastes from hemolymph without a filtration step
  - Insects produce a relatively dry waste matter, mainly uric acid

Vertebrates

- In vertebrates and some other chordates, the **kidney** functions in both osmoregulation and excretion
  - The kidney consists of tubules arranged in an organized array and in contact with a network of capillaries
- The excretory system includes ducts and other structures that carry urine from the tubules out of the body

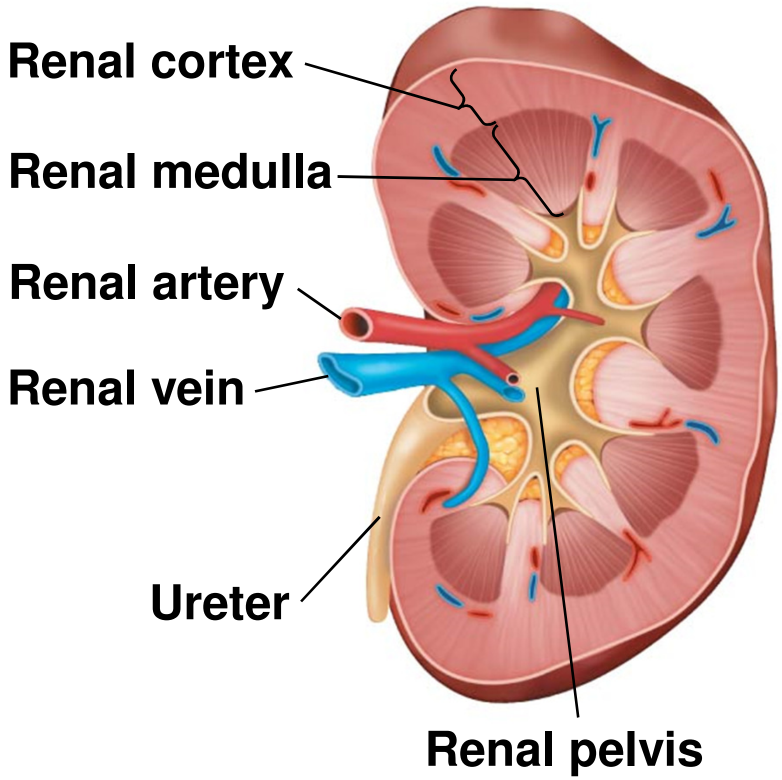
Excretory Organs

- Urine produced by each kidney exits through a duct called the **ureter**
- 2 ureters drain into the **urinary bladder**
- Urine is expelled from the bladder through a tube called the **urethra**



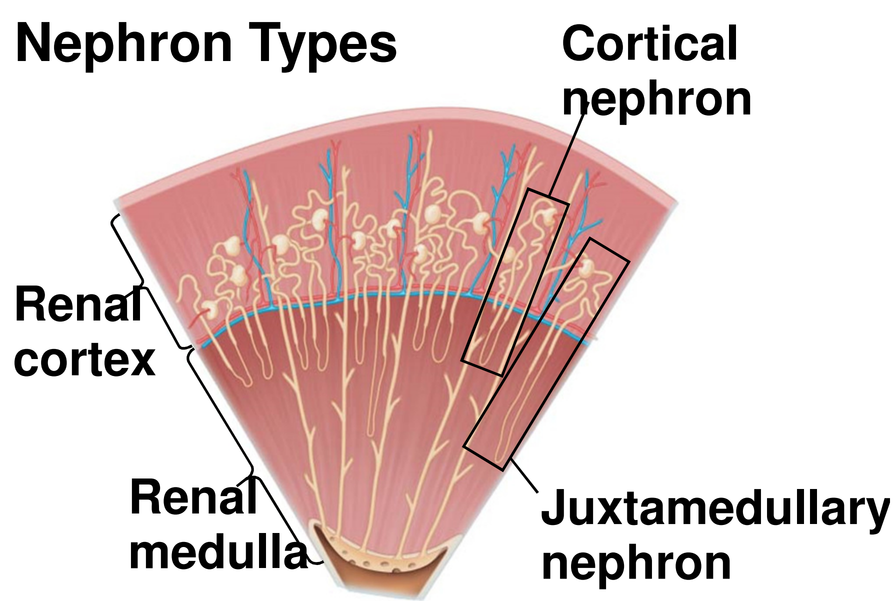
Kidney Structure

- Each kidney has an outer **renal cortex** and an inner **renal medulla**
  - Supplied with blood by a renal artery drained by a renal vein
- Inner renal pelvis collects urine from excretory tubules and passes it to urinary bladder



Nephron Types

- Functional units of the vertebrate kidney are called **nephrons**
  - **Cortical nephrons** reach only a short distance into medulla
  - **Juxtamedullary nephrons** extend deep into the medulla
    - Essential for production of urine that is hyperosmotic to body fluids

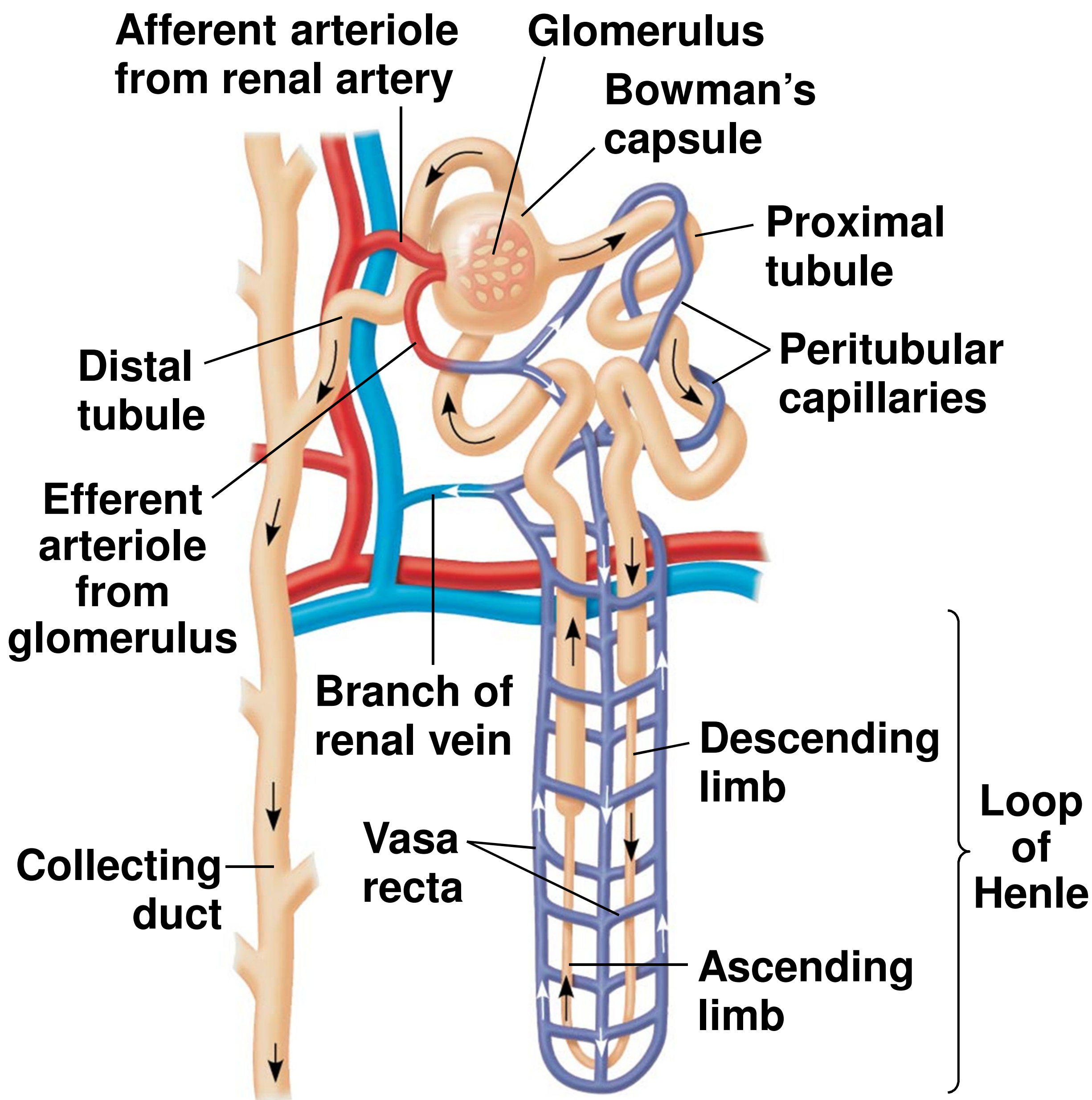


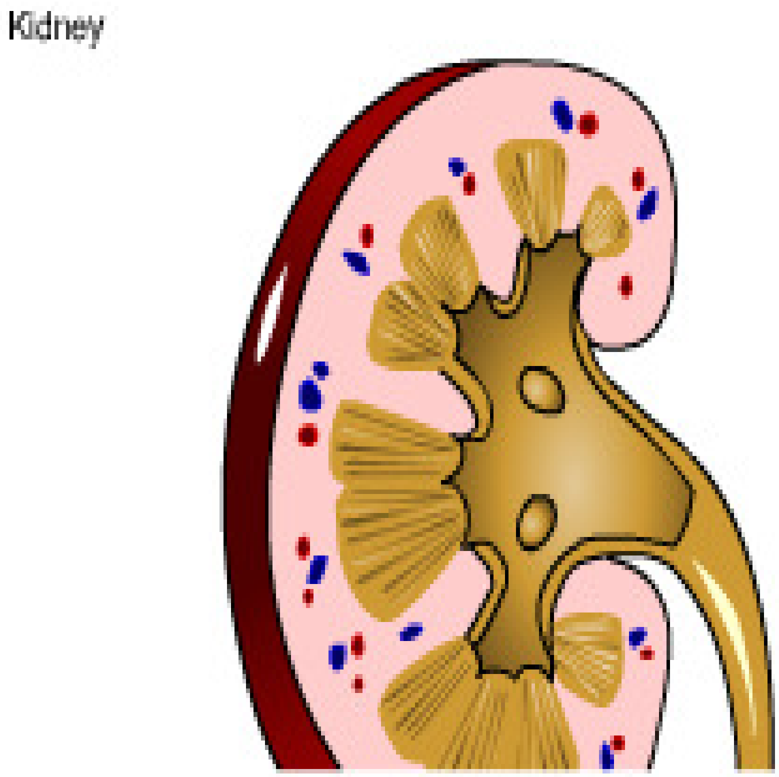
Nephron Organization

- Each nephron consists of a single long tubule and a ball of capillaries called the **glomerulus**
- Blind end of tubule forms a cup-shaped swelling called **Bowman's capsule**, which surrounds the glomerulus
  - Filtrate forms here
- Processing occurs as filtrate passes through 3 major regions of nephron
  - **Proximal tubule**
  - **Loop of Henle**
    - Hair-pin turn with descending and ascending limbs
  - **Distal tubule**
- A **collecting duct** receives processed filtrate from many nephrons and transports it to the renal pelvis

Figure 32.19bc

Nephron Organization





Animation: Nephron Introduction
Right click slide / Select play

Concept 32.4: Hormonal circuits link kidney function, water balance, and blood pressure

- The capillaries and specialized cells of Bowman's capsule are permeable to water and small solutes but not blood cells or large molecules
- The filtrate produced there contains salts, glucose, amino acids, vitamins, nitrogenous wastes, and other small molecules

From Blood Filtrate to Urine: *A Closer Look*

Proximal tubule

- Reabsorption of ions, water, and nutrients takes place in the proximal tubule
- Molecules are transported actively and passively from the filtrate into the interstitial fluid and then capillaries
  - As salt moves from the filtrate to the interstitial fluid, water follows by osmosis
- Some toxic materials are actively secreted into the filtrate

Descending limb of the loop of Henle

- Reabsorption of water continues through channels formed by **aquaporin** proteins
- Movement is driven by the high osmolarity of the interstitial fluid, which is hyperosmotic to the filtrate
- The filtrate loses water and becomes increasingly concentrated all along its journey down the descending limb

Ascending limb of the loop of Henle

- The ascending limb has a transport epithelium that lacks water channels
  - Impermeable to water!
- Here, salt but not water is able to move from the tubule into the interstitial fluid
- The filtrate becomes increasingly dilute as it moves up to the cortex

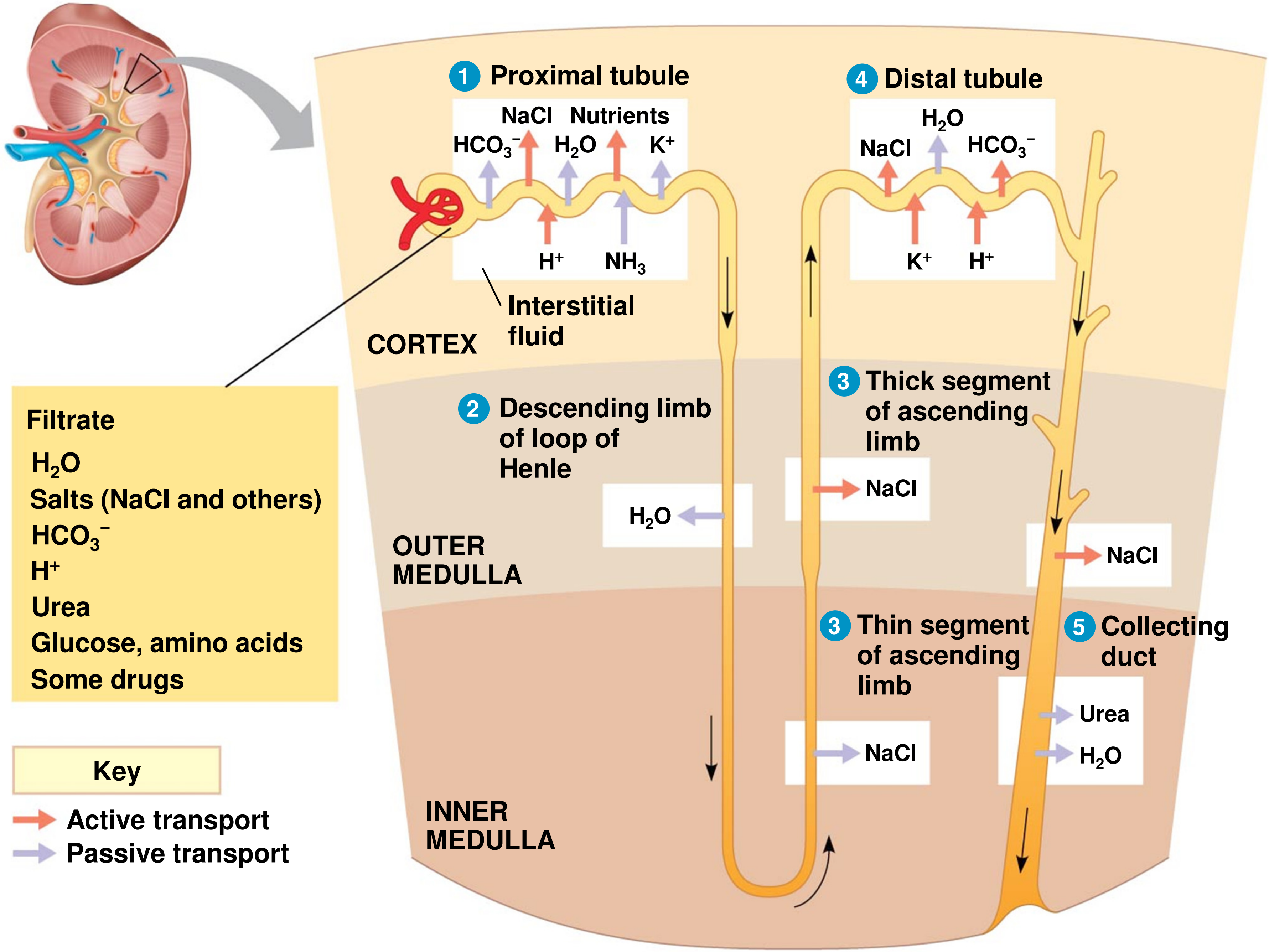
Distal tubule

- The distal tubule regulates the K^+ and NaCl concentrations of body fluids
- The controlled movement of ions contributes to pH regulation

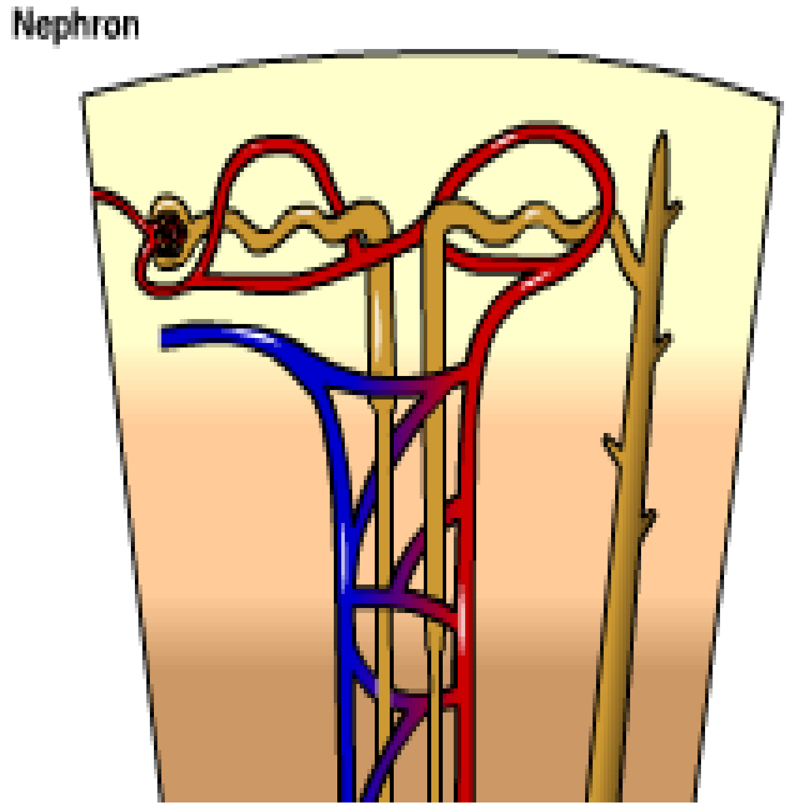
Collecting duct

- The collecting duct carries filtrate through the medulla to the renal pelvis
- Most of the water and nearly all sugars, amino acids, vitamins, and other nutrients are reabsorbed into the blood
- Urine is hyperosmotic to body fluids

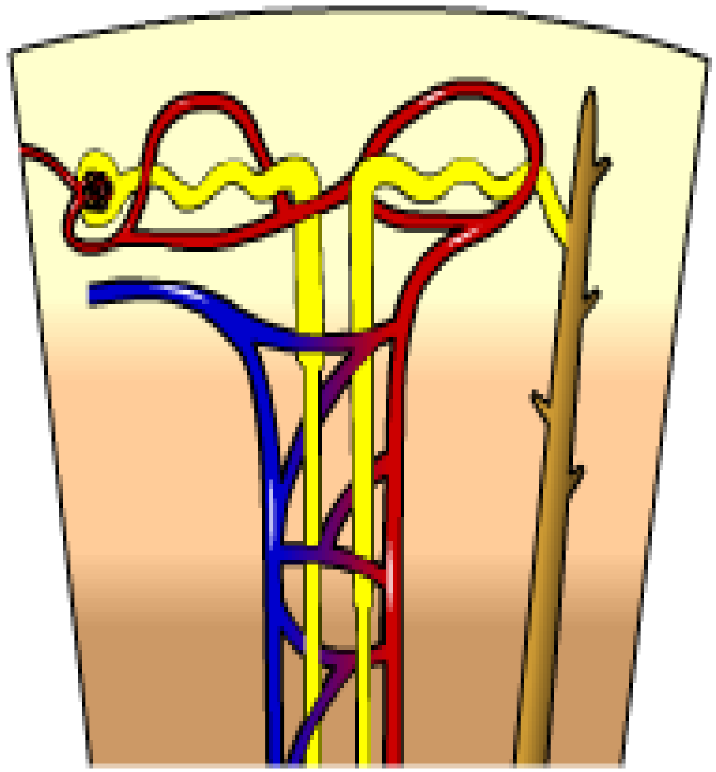
Figure 32.20



1 Proximal tubule
NaCl
Nutrients
HCO_3^-
H_2O
K^+
H^+
NH_3
Interstitial fluid
CORTEX
4 Distal tubule
H_2O
NaCl
HCO_3^-
K^+
H^+
Filtrate
H_2O
Salts (NaCl and others)
HCO_3^-
H^+
Urea
Glucose, amino acids
Some drugs
2 Descending limb of loop of Henle
H_2O
3 Thick segment of ascending limb
NaCl
OUTER MEDULLA
NaCl
3 Thin segment of ascending limb
NaCl
5 Collecting duct
Urea
H_2O
INNER MEDULLA
Key
Active transport
Passive transport

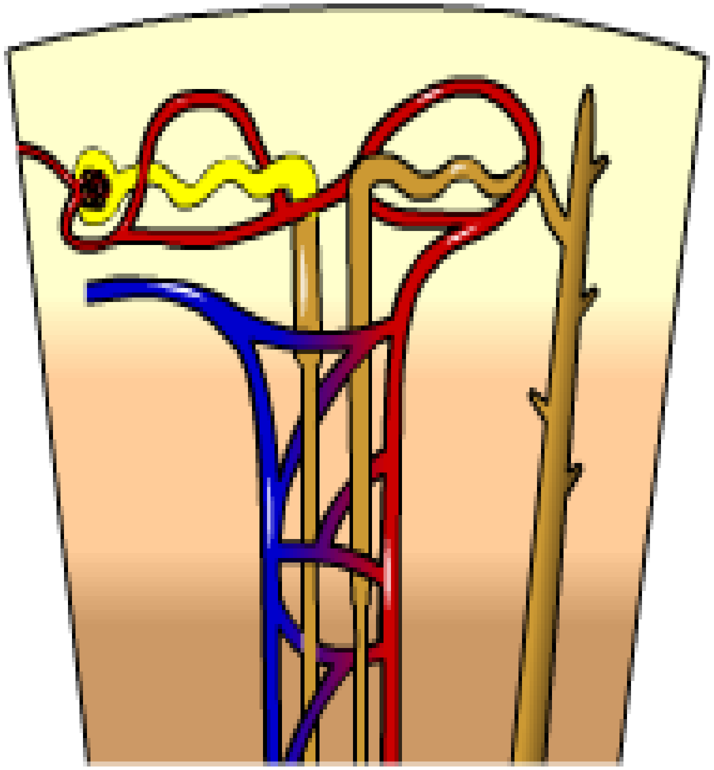


Animation: Bowman's Capsule
Right click slide / Select play



Animation: Collecting Duct

Right click slide / Select play



Animation: Loop of Henle

Right click slide / Select play

Concentrating Urine in the Mammalian Kidney

- The mammalian kidney's ability to conserve water is a key terrestrial adaptation
- The loop of Henle and surrounding capillaries act as a type of countercurrent system
  - Involves active transport and thus an expenditure of energy
  - Maintains a high salt concentration in the interior of the kidney, enabling the kidney to form concentrated urine
- Such a system, which expends energy to create a concentration gradient, is called a **countercurrent multiplier system**

Adaptations of the Vertebrate Kidney to Diverse Environments

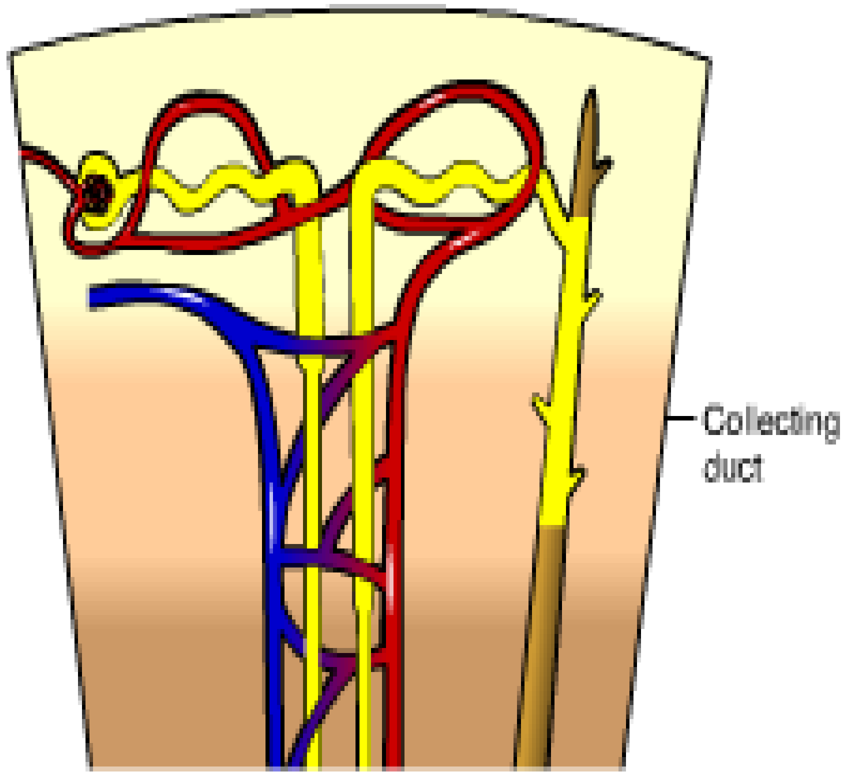
- Variations in nephron structure and function equip the kidneys of different vertebrates for osmoregulation in their various habitats
  - Desert-dwelling mammals excrete the most hyperosmotic urine and have long loops of Henle
  - Birds have shorter loops of Henle but conserve water by excreting uric acid instead of urea
  - Mammals control the volume and osmolarity of urine

Homeostatic Regulation of the Kidney

- A combination of nervous and hormonal inputs regulates the osmoregulatory function of the kidney
- These inputs contribute to homeostasis for <u>blood pressure and volume</u> through their effect on amount and osmoregulatory of urine

Antidiuretic Hormone

- **Antidiuretic hormone (ADH)** makes the collecting duct epithelium temporarily more permeable to water
  - An increase in blood osmolarity above a set point triggers the release of ADH, which helps to conserve water
  - Decreased osmolarity causes a drop in ADH secretion and a corresponding decrease in permeability of collecting ducts



Animation: Effect of ADH

Right click slide / Select play